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16. ABSTRACT

The Port Valdez intertidal sediment system was studied for three years. Physical, geological, geochemical, hydrocarbon, and biological features were examined. Sediments were poorly sorted gravels to plastic clays, and had low amounts of organic matter. Bacterial numbers varied from site to site, and decreased in numbers with depth. Meiofauna consisted primarily of nematodes and harpacticoid copepods. Most meiofaunal species were restricted to the upper three centimeters throughout the year. Meiofaunal densities were typically highest in summer and lowest in winter. Reproductive activities of copepods tended to be seasonal with only one species reproducing throughout the year. Bacterial populations were unaffected by single applications of up to 2000 ppm of Prudhoe Bay crude oil or by chronic applications. It is concluded that oil is removed rapidly by tidal action. Three species of copepods exposed to oil in the field significantly increased in density in experimentally oiled plots. Uptake and release of added oil by intertidal sediments and the clam *Macoma balthica* were examined in the field. Petroleum was not detectable two months after application to sediments. Penetration of oil into sediments to depths beyond one centimeter does not appear to be an important process. During the experimental period, a significant increase in mortality was noted for *M. balthica* exposed to oil. It is suggested that this widely distributed clam may be a valuable indicator for oil.

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THE SEDIMENT ENVIRONMENT OF PORT VALDEZ, ALASKA:

The Effect of Oil on This Ecosystem

by

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FOREWORD

Effective regulatory and enforcement actions by the U.S. Environmental Protection Agency would be virtually impossible without sound scientific data on pollutants and their impact on environmental stability and human health. Responsibility for building this data base has been assigned to EPA's Office of Research and Development and its 15 major field installations, one of which is the Corvallis Environmental Research Laboratory (CERL).

The primary mission of the Corvallis Laboratory is research on the effects of environmental pollutants on terrestrial, freshwater, and marine ecosystems; the behavior, effects and control of pollutants in lake systems; and the development of predictive models on the movement of pollutants in the biosphere.

This report provides a comprehensive discussion of a three-year study of the tidal flat sediment system of Port Valdez, Alaska, and the effects of oil on this ecosystem.

A.F. Bartsch
Director, CERL

ABSTRACT

The tidal flat sediments of Port Valdez, Alaska display significant variations in lithological, chemical, and biological subfacies. These variations are attributed to lateral changes in tidal energies and distances from rock outcrops. The tidal flat deposits are poorly sorted, vary from gravels to plastic clays with various admixtures of sand and silt, have low intercalated organic matter, and are constituted chiefly of physically weathered glacial flour.

Simulated crude oil spills resulted in no changes in the sediment load, nickel, vanadium and organic carbon content. Only under chronic oil dosages did copper and zinc concentrations increase. The general lack of chemical change in oiled sediments is attributed to (1) inability of glacial sediments to immobilize crude oil and its degradable products, and (2) the swift tidal removal of the oil from tidal flat surfaces.

Sediment samples from three intertidal sites in Port Valdez were processed and numbers of filamentous fungi, bacteria and yeasts occurring at various depths in the sediment profile tabulated. Numbers of fungi were low and there was a general decrease in numbers with increased depth. Bacterial numbers varied from site to site but also exhibited a decrease in numbers with depth. Bacterial forms were largely gram negative rods. Fungi were found to be common terrestrial forms of types often isolated from Alaskan soils.

Monthly meiofaunal counts were made at a mid-tide station on three beaches in Port Valdez over a two-year period from 1972 through 1974. Additional beaches within Port Valdez and in Galena Bay were sampled when time and logistics permitted. The meiofauna consisted primarily of nematodes and harpacticoid copepods with representatives of the Protozoa, Cnidaria, Platyhelminthes, Nemertinea, Annelida, Tardigrada, and Arthropoda (ostracods, cumaceans and arachnids) present. Several small macrofaunal species were also sampled with representatives of Annelida, Mollusca, and Arthropoda found. Most of the meiofaunal species were restricted to the upper three centimeters of sediment. No seasonal differences in vertical distribution were noted.

Distinct seasonal patterns of abundance of meiofauna were observed with densities tending to be highest in the summer and lowest in the winter. High winter meiofaunal densities were recorded in the winter of 1972 through 1973. Total meiofauna population values reached a maximum of 4682 individuals per 10 cm^2 in August 1973. Limited information is presented on the reproductive biology of several harpacticoid copepods with only one species, *Halectinosoma gothiceps*, apparently reproducing throughout the year.

A macrofaunal clam species, *Macoma balthica*, was most abundant in July and early August with many recently settled young present.

The biology of the harpacticoid copepod *Harpacticus uniremis* Kröyer was studied for three years on an intertidal beach in Port Valdez, Alaska. The species shows a relatively distinct reproductive period with a single brood of eggs produced approximately 9 to 10 months after insemination. The harsh environmental conditions typical of sediment beaches in Port Valdez and the resultant selective pressures acting on *H. uniremis* there have resulted in high fecundity. Males do not live longer than six months while the longevity of females is at least ten months.

The properties of the silt sediment ecosystem at Port Valdez have important biological consequences that affect the ability of bacterial population to degrade additional organic material. The bacterial populations were unaffected by single applications of up to 2000 ppm of oil, or by chronic applications applied for several consecutive days during several low tide series. However, when the sediment was enriched *in situ* by algal growth and oil seepage and in *in vitro* model systems, the bacteria responded with an increase in biomass, an increase in respiratory activity, and the formation of a sulfide system in sediment columns. Except for heterotrophic H_2S-producing bacteria, the sulfur cycle bacteria were present in very low numbers. It is concluded that oil and other organic matter are removed by tidal action, leaving an organically poor and relatively biologically inactive ecosystem.

Three species of copepods (*Harpacticus uniremis*, *Heterolaophonte* sp., *Halectinosoma gothiceps*) exposed to various levels of oil (200, 500, 1000,

and 2000 ppm) in the field significantly increased in density within a variable number of oiled plots. Two of the species, *H. gothiceps* and *Heterolaophonte* sp., also demonstrated an increase in reproductive activity in some of the oiled plots. The statistically significant increase in numbers of individuals in conjunction with the increase in reproductive activity for these species suggest that density increments are primarily a reflection of heightened reproductive activity. On the other hand, the slight increase in numbers of *H. uniremis* in some of the oiled plots could be the result of an attraction of the copepod to oil since this species was not reproducing during the experimental period. The responses of the copepods to oil in Port Valdez are in contrast to observations made in the laboratory elsewhere in which crude oil fractions were found to be toxic to various species of pelagic copepods. Further experimental work is recommended to fully comprehend the results of our experiments.

The uptake and release of added Prudhoe Bay crude oil by intertidal sediments and by *Macoma balthica*, a resident of those sediments, has been studied at Port Valdez, Alaska. Under the experimental conditions used, petroleum was no longer detectable two months after a five day oiling procedure designed to simulate the stranding of a light oil slick. During the experimental period a significant increase in mortality was noted for *M. balthica* exposed to oil as compared to the clams in the unoiled control plots.

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SECTION I

CONCLUSIONS

The tidal flat sediments of Port Valdez display wide lateral variations in lithological, chemical and biological subfacies. These variations are generally a function of variations in tidal energies, and distances from rock outcrops. Within a radius of about 15 m from rock outcrops the tidal flat is carpeted with very poorly sorted gravels, supporting a dense growth of *Fucus* and a few barnacles at the highest tide mark. At the toes of these gravel deposits, growth of profuse colonies of *Mytilus edulis* is often promoted. At the mid-tide horizon (0.0 m mean tidal height) the sediments, to a depth of 16 cm, consist of homogenous plastic muds. The surficial 4 cm of these sediments are well oxygenated, slightly alkaline (pH 7.2 to 7.4), and contain interstitial waters that have invariably higher salinity than the overlying sea water. Around the 1.0 m tidal horizon (behind Ammunition Island) the tidal flats are composed of either muddy sands, sandy muds, or muds with the granulometric composition depending largely on microrelief. A few low mounds of this latter area have muddy sands and seem to constitute the most suitable habitat for the clam *Macoma balthica*. The surficial 3 cm of these deposits are well oxygenated; however, the subsurface layers are anoxic with a little precipitated but no dissolved sulfide present. In the upper tidal flat area, particularly north of the rocky islands, where tidal turbulence is relatively low, deposition of muds and dense growth of algae (e.g. Chlorophyta, *Monostroma* and *Ulva*) are facilitated. Under putrefying algal masses the sediments are anoxic, and the presence of both dissolved as well as precipitated sulfide is quite evident in them. The distal ends of the tidal flats are constituted of marsh with muddy substrata.

Generally, the tidal flat sediments are very poorly sorted, and have low intercalated organic matter. These sediments are composed of glacially derived flour generated under intense physical rather than chemical weathering conditions, as suggested by the overall clay mineralogy and the lack of chemical fractionation in any sediment based on size grades.

Chemical analysis of gravel-free gross sediments at the mid-tide horizon showed the following heavy metal concentrations: Cu = 53 ppm; Pb = 33 ppm; Zn = 117 ppm; Ni = 79 ppm; and V = 265 ppm. No significant change in the concentrations of Pb, Ni, V, organic carbon, and the anoxic-oxic conditions in sediments were discerned at the above tidal horizon, subsequent to addition of various dosages of Prudhoe crude oil. A notable increase in the Cu and Zn concentrations was discernible only under conditions of chronic oil dosages. An overall lack of change in oiled sediment chemistry is most likely attributable to swift tidal removal of the crude oil from the tidal flat surfaces, and also to the inability of the glacially weathered sediments to immobilize metals that are either complexed with hydrocarbons or are released from the degradation of the latter.

The number of fungi isolated from sampling sites was low, and there was a general decrease in numbers with increased depth. The sampling site in the area of Old Valdez appeared to be the richest in fungal flora. Forty-seven species of microfungi were isolated from this site. The latter area was subject to constant seepage from oil tanks damaged during a serious earthquake in 1964. The known genera of fungi did not include any typically marine organisms. Yeast species appeared to be more cosmopolitan in distribution than the filamentous fungi. Aerobic bacteria were most numerous at the Island Flats study site, and anaerobes were most abundant at Mineral Creek. Ninety-two percent of the bacterial isolates tested proved to be gram negative rods.

The sediment-dwelling meiofauna was examined over a two-year period, and was shown to be relatively diverse in types as well as numbers of organisms present. The faunal abundance and general composition of major taxa collected compare favorably with that found for intertidal flats studied in north temperate regions. Meiofaunal representatives of nine phyla were collected; species with adaptations for an interstitial way of life were rare. The fine sediments characteristic of Port Valdez appear to preclude species with an interstitial way of life. Nematodes were the most abundant organisms found, harpacticoid copepods were second in overall abundance. Nematodes ranged from 172 to 3496 individuals per 10 cm^2, harpacticoids from 26 to 1329 individuals per 10 cm^2, and total meiofauna from 209 to 4682 individuals per 10 cm^2. Differences in meiofaunal composition appear to be related to the sediment characteristics of the particular area. The study sites with somewhat coarser sediments (Mineral Creek and Island Flats) contained a larger percentage of harpacticoid copepods as well as a greater number of individuals of each species than that found in the finer sediment beaches (Dayville Flats). Meiofaunal organisms occurred primarily in the upper three centimeters of sediment. It is probable that the presence of an anoxic environment in the subsurface sediments in Port Valdez restricts the meiofauna to the surficial sediments. No seasonal vertical movements of meiofauna were noted in Port Valdez. The sediment-dwelling copepods of Port Valdez cannot tolerate the very low salinities characteristic of the overlying waters there in the spring and summer, and die rapidly if exposed to salinities less than 6 °/₀₀. Thus, the relative stability of the interstitial salinity of the surface sediments makes survival possible there. Alteration of intertidal sediments by industrial activity could alter the salinity-stability characteristics of the sediments there with resultant loss of intolerant species. Densities of meiofauna can typically be expected to vary directly with water and sediment temperatures. However, unusually high temperatures in the late fall and early winter can be expected to cause brief surges of reproductive activity at this time, but the dramatic decrease in density of these resurgent populations when the temperature drop once again suggests that these density peaks are not important to the general recruitment of meiofauna on the Port Valdez beaches.

The life history of one species of harpacticoid copepod, *Harpacticus uniremis*, was examined in detail, and a number of features of its biology was determined. Some of these features should be useful for monitoring beaches in Port Valdez in the future. A pattern of high densities of *H. uniremis* during spring and summer months and low numbers during fall and winter months generally persisted throughout the study. The species has a distinct seasonal reproductive period with the maximum number of ovigerous females occurring in late winter and early spring. Ovigerous *H. uniremis* aggregate significantly ($\alpha = 0.05$) at the mid-tide region. In the months with the greatest densities of copepods, primarily adult, non-ovigerous females were present. Conversely, the months with lowest copepod densities typically had a more heterogeneous composition. The months of highest densities of *H. uniremis* at Dayville Flats were typically those months with highest water temperatures and highest sediment surface temperatures. Males of the year reach maturity first and grasp copepodid females of their own generation. Copepod maturation, the appearance of males in the population, and copulation takes place primarily in late winter and early spring. Males typically disappear from the population in May. Only adult females presumably carrying spermatophores remain throughout the summer and fall.

The application of modest amounts of oil to the surface of silt sediment deposits typical of Valdez Arm, may be expected to have little or no overt effect on the microbial population. This is due, in part, to the physical characteristics of the sediment and the relatively mild effect of tidal movements, which, in combination, prevent entrance of oil into the sediment and cause its rapid removal to the water column. Even though there may be some changes in the types of bacteria present due to oil enrichment, the observed increase in the number of the bacteria-grazing harpacticoid copepods may have been one factor which prevented any increase in bacterial standing biomass.

It is probable that meiofaunal trends in species and density composition in Port Valdez will have to be documented primarily by qualitative methods in view of the distributional patchiness of many of the species present. However, baseline studies accomplished in the investigation suggest that it will be possible to recognize gross changes in meiofaunal composition with time and that continuing meiofaunal studies on selected beaches should indicate if oil is affecting meiofauna there. The field experiments carried out to test the effects of Prudhoe Bay crude oil on three species of harpacticoid copepods indicated that at the concentrations used (200, 500, 1000 and 2000 ppm), the copepods were either not adversely affected or increased in numbers in the presence of oil. It is suggested that these density increases are the result of an increase in copepod reproductive activity and/or attraction by copepods to the oil. Such a positive response to oil must be further tested in the field and the laboratory, but data do suggest that such density increases in copepods might be useful for monitoring purposes.

Under the specific set of experimental and environmental conditions in which the oil additive experiments were accomplished in the field, petroleum was no longer detectable two months after application. Penetration of petroleum into the sediments to depths beyond one centimeter does not appear to be an important process. Rather, as was suggested by the sedimentological and microbiological studies, it seems that oil is largely removed from the surface of the sediments by the rinsing action of the tides and to a lesser extent by biological activities. During the experimental period, a significant increase in mortality for *Macoma balthica* exposed to Prudhoe Bay was demonstrated, with clams dying *in situ*. These clams, when exposed to soluble fractions of Prudhoe Bay crude oil and to oil-contaminated sediment in the laboratory, responded in an apparently different manner than clams exposed to oil in the field. Buried animals in the laboratory tended to move to the surface while organisms at the surface when exposed to the oil tended to remain there. The somewhat dissimilar results obtained in field and laboratory experiments may be compatible. It is suggested that perhaps clams moved to the surface initially in some of the oiling experiments in the field, but were soon removed by predator activity and movement of tidal waters.

SECTION II

RECOMMENDATIONS

Many of the conclusions arrived at in this study are to be considered tentative. Intensive baseline data on granulometric and chemical composition of sediments have been gathered from a limited area around a reference stake at the mid-tide level of Island Flats, Port Valdez, Alaska. Throughout our studies it has been assumed that this area typically represents much of the tidal-flat environment of the Port Valdez region. As alluded to in the text, this assumption is valid only to a limited extent, because the presence of definite lateral variations have been discerned in lithological, biological, and chemical subfacies in any one of the several tidal flat environments of Port Valdez. Thus, it is suggested that baseline studies be extended to other tidal horizons.

The study of sediment chemistry following simulated oil spills has also been conducted in a limited area, i.e., the mid-tide horizon. No attempt has been made to check the precision of the results on sediment geochemistry following the oil experiments. Therefore, it is advisable that at least three separate oil experiments be conducted and replicate samples from each experiment be statistically analyzed to determine the variability present between analyses. Perhaps on the basis of such a series of rigorous experiments, it may be possible to predict with greater confidence the impact of Prudhoe crude oil on sediment chemistry. Without additional experimental data, it is suggested that extrapolation of the present results to all of the tidal flats in Port Valdez be made with caution.

Microbiological sampling accomplished to determine distribution and abundance of sediment-dwelling microflora in Port Valdez marine sediments was only carried out once during the summer of 1972. Thus, no information is available for seasonal variation of the bacterial populations; more frequent sampling in future investigations is recommended. Since microorganisms were found at all depths sampled, future cores should be taken to greater depths to determine the maximum depth of microbial activity in the area. In addition to a further detailed taxonomic study, an attempt should be made to determine the precise role of these microorganisms as decomposers of detritus. However, the role of the microorganisms in the sediments of Port Valdez can be fully resolved only after detailed determinations of live biomass and secondary productivity potentials. The effects of long term, continuous, but low level organic enrichment of the surface sediments should be examined. The ability of the native bacterial species to establish "sulfide" systems suggests that continuously available organic nutrients may allow the establishment of a more biologically active ecosystem. Similarily, continuous enrichment with inorganic nutrients, particularly phosphate and nitrogen, may result in surface growth of algae, with resulting development of associated bacterial and meiofaunal species. Some other areas, with similar physical characteristics to those observed in Valdez Arm (i.e., upper Cook Inlet), show visible algal growth and marked production of sulfide below the algae mats.

Although a preliminary basis for understanding the sediment meiofauna in Port Valdez has been derived from a two-year study, interpretation of the extreme seasonal fluctuations of organisms here from year to year can only be resolved by further sampling prior to oil-port activity. Contamination from the port facility and tanker operation may cause some changes in meiofaunal composition and density. Documentation of changes in population structure over a substantial time base is a necessary prerequisite if ultimate development of a meiofaunal monitoring program is to be considered.

The copepod *Harpacticus uniremis* appears to be an excellent target organism for use in monitoring the sediment environment in Port Valdez. Suggestions are included here to refine our understanding of this organism prior to its use for monitoring purposes: (1) Additional information is needed for seasonal understanding of the distribution of the copepod on beaches; transects extending from high water to shallow subtidal localities should be occupied. (2) Additional data on a bimonthly basis should be collected: e.g., quantitative meiofaunal samples at the 0.0 m tidal level, sediment organic carbon data, environmental information, and monthly chlorophyll levels. (3) A continuing examination of sex ratio, percent of females with eggs and fecundity should be made as a basis for understanding changes in reproductive behavior when oil port operation begins. (4) The nauplius of *H. uniremis*, a stage that is probably very susceptible to environmental stress, should be identified. (5) The food habits of nearshore demersal fishes should be examined to determine if the copepod might serve as an important trophic link between the Port Valdez intertidal sediment system and these large organisms.

Three species of copepods examined in sediments exposed to various levels of crude oil were not adversely affected by their exposure, and, in fact, tended to show statistically significant increases in numbers in some of the test plots as well as an increase in reproductive activity in two of the species. Further field and laboratory studies are needed to fully understand the copepod-oil relationships demonstrated by the copepods used in the short-term experiments discussed in this report. Also, long-term data are needed to determine the effects, on copepods, of the continuing presence of soluble oil fractions in the overlying water column and in the sediment.

Under the specific set of experimental and environmental conditions used to add oil to the sediments, penetration of petroleum into the sediment depths beyond one centimeter does not appear to take place, and petroleum is no longer detectable two months after application. These petroleum-sediment interactions, as well as other characteristics of the sediment systems on the beaches studied in Port Valdez, are sufficiently different from sediment systems elsewhere that further study and comparison with other Alaskan intertidal systems appear necessary.

Investigation of the clam *Macoma balthica* should be continued to further assess its potential as an indicator of oil pollution and to increase our understanding of the biological basis for the responses of this clam to crude oil as observed in the investigations reported here. Consideration should be given to *M. balthica* in the design of baseline and monitoring studies of marine intertidal sediment systems where this species is present.

SECTION III

GENERAL INTRODUCTION

Valdez, a small town located in Prince William Sound, has been selected as the southern terminus for a pipeline transporting oil from Prudhoe Bay, Alaska to the sea. Initially, the terminal at Valdez will process 600,000 barrels of oil per day, but will be capable of considerable expansion. Numerous tankers will ply the waters of the Sound, either with oil-contaminated ballast or fully loaded with crude oil received from the terminal. It is assumed that some spillage will take place during the extensive operations necessary to handle and ship such vast quantities of crude oil. Additional contamination can be expected when tankers empty their ballast tanks at dockside. At this time, water will be pumped from the ship to a shore station where oil on the surface of the ballast water will be removed, and the effluent returned to the sea. Some hydrocarbon fractions will be returned to the environment with this effluent.

The waters of Prince William Sound show a mixed tidal pattern with two unequal high and two unequal low waters for each lunar day. Extreme fluctuations (up to 6 m) take place during periods of spring tides when the highest and lowest tides of the year occur. Waters containing petroleum fractions will be carried high on the shore twice daily during these periods, and some of these fractions will spread over the sediment surface as the waters ebb. The extreme high tides at this time bring saline waters to pink salmon (*Oncorhynchus gorbuscha*) spawning areas located at the upper reaches of the intertidal zone, and any oil carried by these tidal waters to such areas could pose a potential threat to developing eggs, young, and adults there.

Oil spills in highly turbulent areas are rapidly dispersed in a few days with biodegradation following soon thereafter, except where large clumps become buried in the sediment. High concentrations of oil combined with some wave action will lead to sinking of heavier fractions, a situation that could occur in Port Valdez where winds of 70 to 100 knots are not uncommon. Ordinarily waters are calm in Port Valdez and in most bays in Prince William Sound, and during such calm periods heavier fractions of oil might be expected to accumulate onshore.

The continuing presence of petroleum fractions in the marine environment of Port Valdez introduces a new complex of variables to organisms residing there, and these factors could have an especially great impact on the infauna and epifauna of intertidal sediments. The heavy petroleum fractions making up oil slicks would be expected to spread over intertidal substrata and their associated fauna at every low tide while soluble fractions would be present as a continuing potential threat at all tides. Thus, the presence of oil in Port Valdez could result in a wide spectrum of potential dangers to intertidal marine life there.

It was the intent of this investigation to intensively examine one component of the marine environment of Port Valdez, the intertidal region, and to specifically investigate the sediment system of a number of beaches there. The objectives of the investigation were: (1) to determine the typical physical, chemical and biological conditions of the sediment ecosystem of three beaches in Port Valdez, and (2) to experimentally examine the physical, chemical and biological effects of Prudhoe Bay crude oil added to the sediments of these three beaches.

SECTION IV

DEPOSITIONAL AND GEOCHEMICAL ENVIRONMENT OF PORT VALDEZ TIDAL FLATS

SETTING OF THE STUDY AREAS

Location and Physiography

Port Valdez is situated in the coastal belt of the Pacific Mountain System of South Alaska (Figure 1). The Port is a glaciated reentrant or fjord in the Chugach Mountains, and is characterized by a long (21 km), narrow (4.5 km), deep body of water that is hemmed in by steep, precipitous, high mountains (150 to 1000 m). It constitutes the northeasternmost arm of Prince William Sound, and the extent of it at its head is restricted by the outwash deltaic complex formed by the debris from the Lowe and Robe Rivers as well as the melt-water streams of the Valdez Glacier.

Port Valdez consists essentially of a flat bottomed and steep-sided glacially carved trough with two sills near the Port mouth. The east-west longitudinal extension of the Port has been defined chiefly by the alignment of the major structural trends of the surrounding lithology which is also east-west.

Climate

The Port Valdez region is subjected to long, severely cold winters and short, cool summers. Although the mean annual air temperature is around 10°C, there can be quite wide variations between the lowest (-34°C in January) and the highest temperatures (21°C in July-August). However, Port Valdez has been recognized as the northern-most ice-free seaport in Alaska. The presence of snow on the ground is evident for nearly 6 to 7 months a year while precipitation on the order of 158 cm/year is considered quite typical (Hood *et al.*, 1973)[1].

General Oceanography

Port Valdez is a positive estuary with a classical estuarine circulation of a seaward movement of brackish water and a landward movement

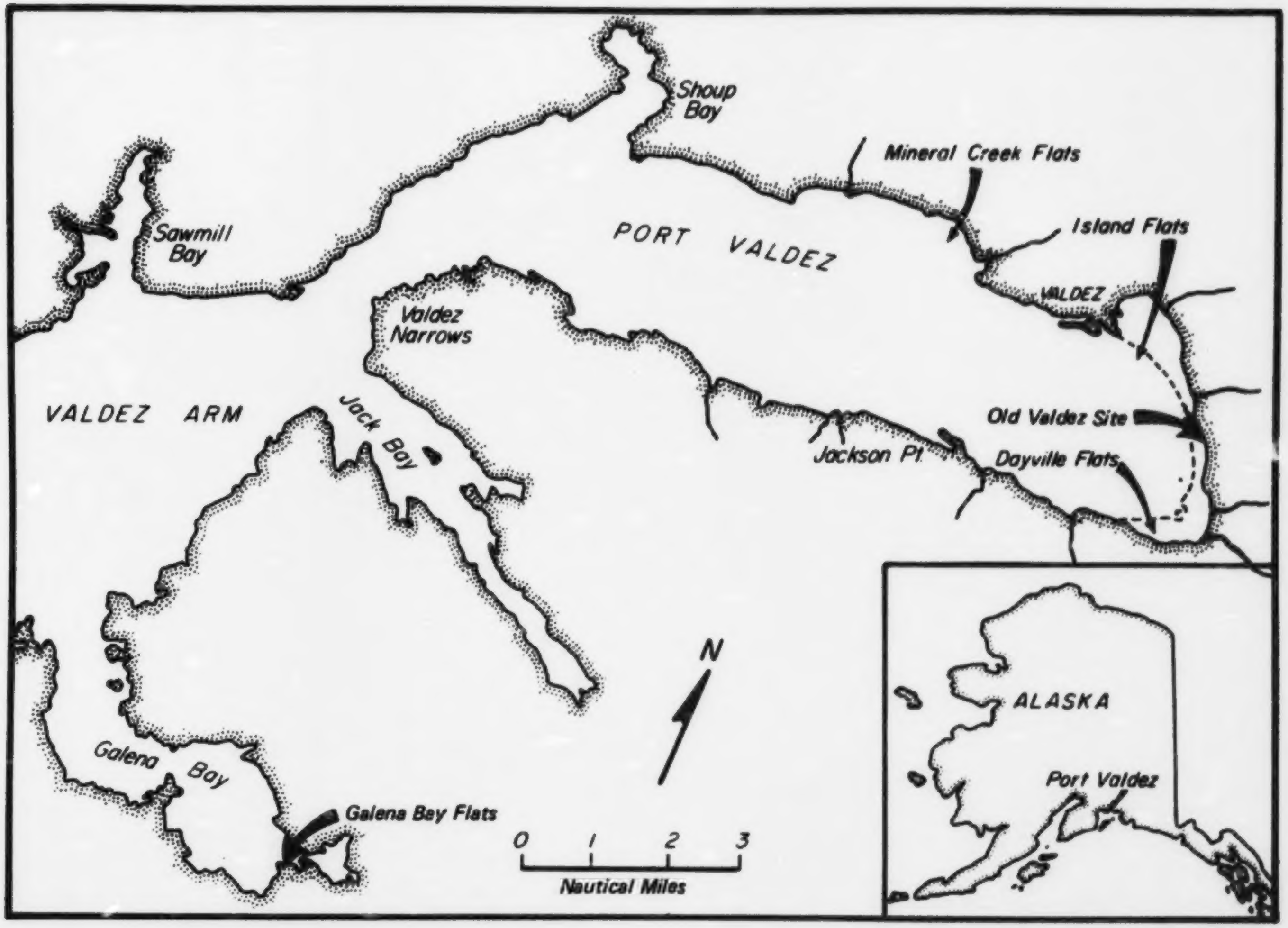

Figure 1. Map of Port Valdez showing the Mineral Creek, Dayville, Old Valdez, and Galena Bay baseline sampling sites as well as the Island Flats experimental area.

of the deeper layers of saline water. Bottom waters are renewed each year during cold months. During winter, freezing air temperatures and limited freshwater runoff result in a renewal of the entire water structure within the fjord. The surface water circulation moves in a counterclockwise gyre; deeper waters oscillate with an apparent net movement into Port Valdez.

Surface water temperatures range from winter minima of < 2.5°C to summer maxima of > 11°C. Below about 75 m most temperatures are in the 3 to 6°C range. In the upper 20 m of the water column, extremely low salinities (< 1.0 °/₀₀) occur during the summer and higher values (32.0 °/₀₀) occur during the winter. Salinities below the upper 20 m vary from about 28 to 32.5 °/₀₀ (Hood *et al.*, 1973)[1].

Geology

The geology of the Port Valdez region is conveniently subclassed into one bedrock unit and three depositional complexes that are comprised of recent sedimentary deposits. The exposed bed rocks have been classed under the Valdez Group of Late Cretaceous age (Moffit, 1954)[2]. Typically, these rocks consist of steeply dipping, thick inter-bedded slate and graywacke, with minor amounts of argillite, arkosic sandstone, and conglomerate. Around Valdez the rocks are closely folded, jointed, as well as foliated in an east-west strike direction. The Valdez Group of rocks has been subjected to intense glacial weathering, as evidenced by the physiography. The recent deposits are the unconsolidated sediments of tidal flats, outwash delta and alluvial fans, and consist of a wide variety of poorly sorted debris. The latter two environments are usually blanketed either by gravels, sandy gravels, or gravelly sands with minor amounts of muds. The tidal flats exhibit significant lateral variations in sediment types; the upper flats generally consist of sandy muds whereas the lower flats consist of muddy sands. Flats adjacent to rock outcrops, as is to be expected, show relatively larger amounts of gravels and rocks which may or may not support a variety of sessile marine floral and faunal communities.

Geological description of the Port Valdez area would be incomplete without a note on seismic activity in the area. Port Valdez is part of an extensive area in Alaska that is continuous with the circum-Pacific belt which is seismically one of the most active zones on earth, and has been subjected to relatively frequent earthquakes of significant magnitude. The last severe earthquake which occurred in March 1964 was followed by large-scale landslides and submarine slumpings in the Port Valdez area resulting in some local changes in coastal geomorphology. The hingeline showing the zero land level change, following the above earthquake, runs almost along the southern edge of Port Valdez (Stanley, 1971[3] after Plafker, 1965[4]). This suggests that the intertidal regions of the study sites at Island Flats and Mineral Creek have been recently lowered while the intertidal study areas in the vicinity of Dayville Flats have been uplifted (Figure 1). In the course of sampling operations we came across several hundred dead bivalves, *Mya arenaria*, partly protruding on tidal flats of the Dayville area. These suspension-feeding mollusks, probably died enmass after the earthquake of March 1964, and have been subaerially exposed because of local uplifting of the region and subsequent erosion of the tidal flat surfaces.

MATERIALS AND METHODS

A mid-tide site (0.0 m tidal height) was selected on each of three tidal flats (i.e., Island Flats, Dayville Flats, and Mineral Creek Flats, (Figure 1) for obtaining sediment samples simultaneously with biological samples.

For the purpose of chemical analysis, sediment core samples were collected in duplicate in short (46 cm) plastic core liners having an internal diameter of 7.6 cm. The core samples were achieved by first driving the liners manually into the tidal flats and then, following a small amount of rotation or digging around the base of the core, the liners loaded with sediments were retrieved. To minimize escape of gases as well as contamination of the samples with atmospheric oxygen, the core liners were quickly capped at the ends and sealed in the field with tape.

Prior to taping, the section of the liner which was devoid of any sediment sample was cut transversely and separated out. This step was taken to ensure that no air pocket was left between the cap and the sediment top. Because of the presence of compacted subsurface clay it was generally not possible to manually drive the plastic liners deeper than 16 cm.

At the field base camp in Valdez, sediments in one of the core liners were pushed out and cut transversely into 4 cm sections, using a teflon-coated stainless-steel knife. The individual sections were then put in plastic bags and stored in a frozen state until grain size, chemical, and clay mineral analyses could be taken up at the Fairbanks laboratory. From a second core sample interstitial water samples were obtained. Approximately 4 cm sections of sediments from the core top were extruded and directly loaded into teflon squeezers in order to express out interstitial water samples. The squeezing unit was similar to that devised by Reeburgh, (1967)[5] and operated under N_2 pressure. To minimize contamination of the interstitial water samples with atmospheric O_2, the entire operation of sediment extrusion from liners and squeezing was conducted in a N_2 atmosphere in a glove compartment. The above procedure was satisfactory for sampling interstitial waters from 4 cm sediment sections, but was not favorable when interstitial water samples were to be desired from 1 cm sections because of limited sediment volumes that can be obtained in a liner of 7.6 cm diameter. As such, successive 1 cm sections from the top to 4 cm depths were scraped from the tidal flats and the squeezers were loaded up to the brim directly in the field, and the sediment samples were stored with mimimum atmospheric contact until ready for squeezing. Invariably these sediments were squeezed within one half hour of the time of collection.

Aliquots of sediment interstitial waters, collected by the above procedure, were directly taken into two separate hypodermic syringes for quantitative colorimetric measurements of dissolved O_2 (Broenkow and Cline, 1969)[6] and H_2S (Cline, 1969)[7]. When necessary, additional sediment sections were taken from the field, squeezed, and interstitial water samples collected for Fe, Mn, and salinity measurements.

Size analysis of sediments was achieved by the combined sieving-pipetting method (Krumbein and Pettijohn, 1938)[8]. The conventional statistical grain size parameters were calculated using the formulae given by Folk and Ward (1957)[9].

Clay mineral compositions in the less than 2 mμ fractions of sediments were analyzed by the X-ray diffraction technique. For routine clay mineral assessments oriented grains were mounted on glass slides and X-rayed after glycolation. However, for the determination of mica (or "illite") and chlorite polytypes, randomly oriented grains were considered. Details on the procedures pertaining to sample treatment, mounting, and quantifying the clay minerals have been elaborated upon elsewhere (Naidu *et al.*, 1971)[10].

Baseline trace element, organic carbon, and carbonate analyses were performed on gravel-free gross sediments. Sediment samples were dried at 110°C and then pulverized into fine powders using an agate mortar and pestle. Semiquantitative triplicate analyses of each of these powders were conducted for 20 elements in an emission spectrograph. Results of the triplicate analyses were averaged to document the baseline semiquantitative abundances of the elements. In addition, quantitative trace element data were obtained by another way. Known portions of the above fine powders were ashed in a platinum crucible, and digested first in concentrated $HF-HNO_3$ acid and then in concentrated HNO_3. The residue was then taken into solution in 10% V/V HNO_3 acid. From the solutions thus obtained the concentrations of Cu, Pb, Zn, Ni, and V were analyzed by atomic absorption spectrophotometry, using a Perkin-Elmer Model 370 unit. Elemental analysis precision was better than 12%, and the accuracies of the analysis were checked by considering the U.S. Geological Survey standard rock sample AGV-1. In order to gather information on the partition patterns of a few elements in the coarse and fine size grades, the mud fraction (< 0.0062 mm size) of selected sediments were separated from gross sediments via wet sieving through a 230 mesh stainless-steel sieve. From the mud fraction thus obtained, the same suite of elements as in case of the gross sediments, were analyzed by atomic absorption spectrophotometry.

Carbonate in the sediments was determined manometrically (Hülsemann, 1966)[11]. Organic carbon abundance in the sediments were calculated from the differences between total carbon and carbonate carbon. Total carbon was estimated in a LECO, TC-12 automatic carbon determinator.

Temperatures were taken routinely during every sediment sample collection with the use of a glass mercury thermometer. The pH of sediments were documented by use of a portable Coleman, Model 37A, pH-Eh potentiometer. The electrodes were directly inserted at various depths on sediment cross-sections and readings were taken when the instrument stabilized. Salinities of sediment interstitial water as well as of the overlying sea water were measured with an inductive salinometer.

The assessment of the oxic-anoxic state of tidal-flat sedimentary regime was approached by various geochemical means, rather than the instrumental measurements of the oxidation-reduction potentials (Eh). Use of the Coleman, Model 37A, pH-Eh potentiometer that was available to us had limited applicability, primarily because of operational difficulties coupled with the recognition of interpretive problems generally encountered in obtaining true Eh of natural environments via instruments such as the above (Whitfield, 1969[12]; Berner, 1971[13]; Machan and Ott, 1972[14]).

In this study the oxic-anoxic nature of sedimentary environments was recorded primarily on the basis of the quantitative analyses of dissolved O_2 and H_2S in interstitial waters, and also on the basis of a simple qualitative analysis to detect the presence or absence of precipitated sulfide. Throughout this study, the presence of dissolved O_2 has been assumed to connote presence of an oxic environment, while the absence of O_2 or presence of H_2S has been assumed to imply an anoxic condition. Fortunately, these geochemical criteria correlated quite well with analysis of bacterial types, change in sediment colours, and density of faunal populations. As such, it is felt that the geochemical methods followed by us for determining oxic-anoxic sedimentary regimes on a routine basis is quite tenable for the Valdez tidal flat area. In attempting to document the baseline composition of some trace elements in the tissues of some indicator faunal and floral species of the tidal flats, random samples of a few algae (e.g., *Monostroma, Ulva,* and *Fucus*) and bivalves (e.g., *Mytilus edulis*, and *Macoma balthica*) were collected from the Island Flats area. At the field base camp samples of each of the species were lightly washed in double distilled water, and any epiphytes on the surface of the organisms removed with teflon-coated tweezers. The floral samples were then cut into small fragments and stored frozen until ready for analysis. The pneumatocysts or floats of *Fucus* were excluded from the analysis. The living bivalves were left in a plastic trough of clear seawater for two days to purge their digestive tracts of all sediment, and the soft parts then removed from the shells and stored in a frozen state. In the Fairbanks laboratory, individual tissue samples were first freeze-dried and then pulverized in an agate mortar and pestle. Weighed portions of the tissues were taken into solution by adopting a simple modification of the nitric acid vapor oxidation method of Thomas and Smythe (1973)[15] via an additional H_2O_2 reaction (Tolg, 1972)[16]. From these solutions, the abundances of Cu, Pb, Zn, Cd, Mo, and Ni were quantitatively measured by atomic absorption spectrophotometry. Mercury in the tissues was analyzed by flameless atomic absorption.

DEPOSITIONAL ENVIRONMENT OF THE TIDAL FLAT COMPLEX

In Prince William Sound, as well as in Port Valdez which forms a part of the Sound, a mixed tidal pattern with two unequal high waters and two low waters is observed for each lunar day. During spring tides in the above area the tidal range can be as high as 6 m. Because of this extensive tidal range and the presence of a blanket of unconsolidated sediments, broad tidal flats have developed locally in Port Valdez on level intertidal ground. In Port Valdez, intertidal regions which are readily exposed to tidal flat developments are generally restricted to the marine-ward margins of outwash deltas and alluvial fans. This report describes the physicochemical characteristics of the depositional environments of tidal flats from three geographic locations at the head of Port Valdez.

An almost continuous semicircle strip of tidal flats borders the seaward margin of the intertidal area between the new town of Valdez and Dayville Flats at the head of Port Valdez. However, there are only two regions along this strip where extensive tidal flats have developed. For convenience, in this report the first area will be called Island Flats because it lies around Ammunition and other adjacent small islands, between the new and old townsites of Valdez. The second area will be called Dayville Flats because of its proximity to a former small town known as Dayville. A third tidal flat area which has been considered for our present study is situated on the marineward margin of the fluvial outwash of Mineral Creek, west of the new township of Valdez, and is isolated from the first two flats by a hillock (Figure 1). Because Island Flats was studied in relatively more detail, most of the description that follows will pertain to that area.

The three tidal flats mentioned above have quite contrasting depositional milieu, primarily because of the differences in their locations, sediment source, and the topography surrounding them. As such, each of the areas will be described separately.

Island Flats

The Island Flats study site is located in an embayed portion of Port Valdez (Figure 1), and has an aerial extent of about 1.6 x 2.4 km. There are significant lateral variations in the physicochemical nature of the surficial deposits within this flat. With the changes in sediment substrate habitat, almost concomitant lateral variations in faunal and floral assemblages can also be detected. The intertidal area south of the chain of islands (Figure 2) is a relatively high energy area as compared to the flat area north of the islands; the former area is exposed directly to the sea and is therefore exposed to more intense tidal current action. However, within the southern tidal flat area three broad subfacies can be recognized. The narrow strip extending from the foot of the easternmost hill of Ammunition Island (Figure 2) to about 15 m south of the island is blanketed with very poorly sorted coarse sediments, consisting chiefly of gravels (generally of boulder, cobble and pebble sizes), subordinate amounts of coarse sand, and traces of mud. The boulders lying next to the hillock and at the high tide mark support dense algal colonies of Chlorophyta and *Fucus*, and a few barnacles. In Figure 2 this sub-environment has been

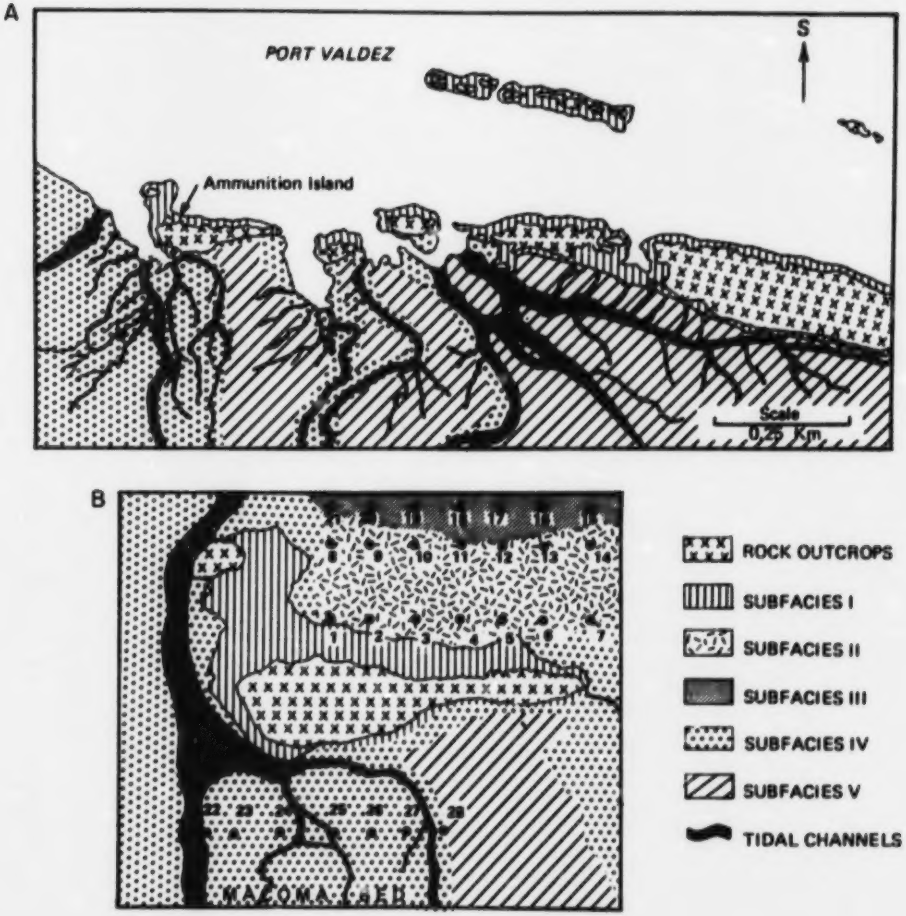

Figure 2. Lithological facies on Island Flats, Port Valdez. A) General areas of investigation. B) Enlarged view of Ammunition Island and study areas. Details based on ground truth and air-photo interpretation.

depicted as SUBFACIES I. Extending seaward to about 60 m from the outward margin of the above subfacies of coarse deposit is a tidal flat area that is dominated by plastic and leathery muddy deposits (< 62 μ) (SUBFACIES II in Figure 2). These deposits may have some gravels (Figure 2; Table 1, Samples 1 to 14), are generally poorly sorted, and have negatively to positively skewed as well as leptokurtic size distributions (Table 2). This subfacies was selected as the site for more detailed meiofaunal investigations, the site lies at the mid-tide level (0.0 m tidal height).

Temperature measurements of intertidal surficial sediments (upper 2 cm) on a monthly schedule in Port Valdez during an entire year showed significant temporal variations (Tables 3 and 4). As expected, these variations followed the seasonal variations in the overlying air and water temperatures, as well as on the presence or absence of snow cover on tidal flats. Sediment temperatures paralleled air temperatures at low tide and water temperatures at high tide (also see Figures 4 and 5 in Section VI). Salinities of sediment interstitial waters generally displayed an overall slight increase in the deeper sections of sediment cores. Further, for any one given month, the interstitial waters of sediments had relatively higher salinities than the tidal waters overlying the sediments (Tables 5 and 6). These results are apparently similar to those obtained by Friedman and Gavish (1970)[17] who observed a general subsurface increase in several major ions (e.g., Cl^-, Mg^{++}, Ca^{++}, Na^+, and K^+)—thus, plausibly salinity also—in interstitial water of continental margin sediments of Long Island area, New York (also see Barnes, 1974[18]; Leppäkoski, 1968[19] for discussion of salinities of interstitial waters). Admittedly, at present we have no definite idea why salinities of the sediment interstitial waters of Port Valdez flats display an increase below the sediment-water interface. A reasonable explanation could be that there are ionic influxes of some major alkali and alkaline-earth elements into the original parcels of entrapped interstitial waters, resulting from postdepositional changes. The slight upward decrease in salinities of interstitial waters in some months presumably reflect the establishment of progressively greater chemical equilibration between interstitial waters and overlying sea waters of core sections that are nearer to the sediment-water interfaces.*

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*Note: Continuation of text on page 38.

TABLE 1

GRAVEL, SAND, SILT, AND CLAY PERCENTS OF TIDAL FLAT SEDIMENTS OF ISLAND FLATS, PORT VALDEZ (SEE FIGURE 2 FOR SAMPLE LOCATIONS). MUD PERCENTS CALCULATED SEPARATELY

Sample No.	Gravel	Sand	Silt	Clay	Mud
VLDZ3/74-1	7.90	35.04	43.43	13.63	57.06
VLDZ3/74-2	5.46	50.31	28.70	15.53	44.23
VLDZ3/74-3	15.77	7.65	70.39	6.19	76.58
VLDZ3/74-4	0.16	13.72	68.18	17.94	86.12
VLDZ3/74-5	4.21	59.98	22.39	13.42	35.81
VLDZ3/74-6	12.40	87.60	-	-	-
VLDZ3/74-7	13.87	86.13	-	-	-
VLDZ3/74-8	18.65	81.35	-	-	-
VLDZ3/74-9	5.70	94.30	-	-	-
VLDZ3/74-10	0.16	1.99	74.84	23.01	98.25
VLDZ3/74-11	0.17	8.32	77.12	14.38	91.50
VLDZ3/74-12	-	1.68	96.45	1.87	98.32
VLDZ3/74-13	-	1.16	95.77	3.07	98.84
VLDZ3/74-14	-	6.01	64.80	29.20	94.00
VLDZ4/74-15	9.21	50.94	20.36	19.48	39.84
VLDZ4/74-16	11.72	74.49	6.96	6.83	13.79
VLDZ4/74-17	12.69	83.73	2.50	1.08	3.58
VLDZ4/74-18	3.68	48.44	22.18	25.71	47.89
VLDZ4/74-19	18.83	16.54	33.31	31.32	64.63
VLDZ4/74-20	4.86	44.66	23.43	27.05	50.48
VLDZ4/74-21	1.25	73.74	11.47	13.53	25.00
VLDZ4/74-22	9.32	65.68	2.50	12.50	15.00
VLDZ4/74-23	-	77.00	16.50	6.50	23.00
VLDZ4/74-24	8.50	77.50	12.30	1.70	14.00
VLDZ4/74-25	2.20	81.80	9.00	7.00	16.00
VLDZ4/74-26	2.00	92.00	4.00	2.00	6.00
VLDZ4/74-27	-	30.00	59.00	11.00	70.00
VLDZ4/74-28	48.90	31.10	6.00	14.00	20.00

TABLE 2

GRAIN SIZE ANALYSIS OF SURFACE AND SUBSURFACE SEDIMENTS TAKEN FROM THE TIDAL FLATS OF ISLAND FLATS, DAYVILLE FLATS, AND MINERAL CREEK, PORT VALDEZ.

Md=MEDIAN; M_z=MEAN; σ_I=SORTING; SK_I=SKEWNESS; K_G=KURTOSIS

Sample	Core Section (cm)	Gravel %	Sand %	Silt %	Clay %	Md(ϕ)	M_z(ϕ)	σ_I	SK_I	K_G
Island Flats										
Core 1	0-1	2.25	75.75	8.50	13.50	1.16	2.95	3.45	0.72	3.26
(at 15 cm above	1-2	5.25	92.75	0.25	1.75	0.95	0.83	0.88	-0.27	1.12
mid-tide level)	2-3	7.00	92.75	0.25	-	0.91	0.77	0.95	-0.29	1.12
	3-4	10.05	89.95	-	-	0.91	0.75	1.09	-0.36	1.31
	4-5	15.00	85.00	-	-	0.87	0.52	1.28	-0.48	1.19
	5-6	36.50	63.50	-	-	0.19	-0.35	1.87	-0.37	0.65
	6-7	35.00	64.75	0.25	-	-0.59	-0.51	1.35	0.09	0.89
	7-8	35.50	63.00	1.50	-	-0.51	-0.59	1.56	-0.13	1.23
Core 2	0-1	-	7.50	47.50	45.00	7.81	7.89	2.52	0.01	1.31
(at mid-tide	1-2	-	13.50	43.50	43.00	7.65	7.61	2.84	-0.02	1.30
level)	2-3	-	3.50	49.50	47.00	7.36	8.09	2.33	0.15	1.13
	3-4	-	8.50	49.50	42.00	7.60	7.77	2.44	0.05	1.23
	4-5	-	1.00	51.50	47.50	7.85	8.11	2.08	0.21	1.04
	5-6	-	0.25	50.75	49.00	7.94	8.24	2.07	0.27	1.09
Surface Sediments at 1 m high-tide level										
No. 22	0-2	9.32	65.68	2.50	12.50	2.70	3.13	3.46	0.22	1.99
No. 23	0-2	-	77.00	16.50	6.50	1.60	2.83	2.73	0.63	1.22

TABLE 2 (Continued)

GRAIN SIZE ANALYSIS OF SURFACE AND SUBSURFACE SEDIMENTS

Sample	Core Section (cm)	Gravel %	Sand %	Silt %	Clay %	Md(ϕ)	M_z(ϕ)	σ_I	SK_I	K_G
No. 24	0-2	8.50	77.50	12.30	1.70	1.70	1.83	2.19	0.11	1.74
No. 25	0-2	2.20	81.80	9.00	7.00	1.30	1.90	2.26	0.50	2.64
No. 26	0-2	2.00	92.00	4.00	2.00	0.70	0.77	1.61	0.13	3.28
No. 27	0-2	-	30.00	59.00	11.00	5.00	4.90	2.18	-0.09	1.36
No. 28	0-2	48.90	31.10	6.00	14.00	-1.00	1.13	4.39	0.67	1.41
Dayville Flats										
	0-1	-	15.00	64.00	21.00	6.52	6.42	2.30	0.04	1.31
	1-2	-	8.50	66.50	25.00	6.60	6.85	2.22	0.21	1.46
	2-3	-	2.50	80.25	17.25	5.77	6.10	2.11	0.41	1.25
	3-4	-	2.50	62.50	35.00	7.31	7.66	2.10	0.30	1.34
	4-5	-	1.50	65.50	33.00	7.12	7.51	1.99	0.32	1.26
	5-6	-	8.00	52.75	39.25	7.25	8.22	3.03	0.37	1.05
	6-7	-	8.00	68.50	21.50	6.41	6.74	2.02	0.25	1.38
	7-8	-	5.50	68.00	26.50	6.77	7.13	2.21	0.32	1.58
	8-9	-	2.00	65.00	33.00	7.22	7.53	1.83	0.32	1.20
	9-10	-	1.25	66.75	32.00	7.15	7.58	1.86	0.41	1.30
	10-11	-	6.75	70.75	22.50	6.45	6.85	2.12	0.32	1.80
	11-12	-	5.50	68.60	26.50	6.80	7.15	2.15	0.29	1.63
	12-13	-	4.00	68.00	28.60	6.91	7.35	2.05	0.39	1.51
	13-14	-	1.50	68.50	30.00	7.05	7.47	1.84	0.40	1.28

TABLE 2 (Continued)

GRAIN SIZE ANALYSIS OF SURFACE AND SUBSURFACE SEDIMENTS

Sample	Core Section (cm)	Gravel %	Sand %	Silt %	Clay %	Md(ϕ)	$M_z(\phi)$	σ_I	SK_I	K_G
Mineral Creek										
	0-1	30.00	53.50	10.50	6.00	0.40	0.71	3.49	0.23	1.21
	1-2	32.25	50.25	11.00	6.00	0.51	0.47	3.67	0.15	1.01
	2-3	19.50	62.25	11.75	6.50	0.96	1.31	3.10	0.29	1.23
	3-4	26.00	55.50	11.00	7.50	0.90	1.09	3.42	0.22	1.16
	4-5	30.50	53.50	9.75	6.25	0.58	0.65	3.43	0.19	1.06
	5-6	34.00	50.75	7.75	7.50	0.20	0.55	3.41	0.32	1.49
	6-7	21.25	60.75	11.50	6.50	1.11	1.25	3.27	0.17	1.20

TABLE 3

TEMPERATURES IN DEGREES CENTIGRADE, AT LOW TIDE IN THE PORT VALDEZ AREA AND OTHER NEARBY LOCATIONS

Date	Location	Water T	Air T	Sediment Surf T	1cm	2cm	3cm	4cm	5cm
May 16, 1972	OV	7.6	6.2	-	-	-	-	-	-
June 11, 1972	D	12.3	13.5	14.5	13.0	12.0	11.5	11.2	11.2
June 27, 1972	D	10.0	12.0	13.5	13.0	12.5	12.5	12.3	12.0
July 10, 1972	D	10.0	17.2	14.0	13.5	13.0	13.0	12.5	12.1
July 11, 1972	D	10.0	16.0	19.5	18.5	17.0	15.6	-	-
July 12, 1972	D	10.0	12.8	15.0	14.5	12.5	11.9	11.5	11.3
July 12, 1972	MC	12.3	13.5	11.5	11.8	10.5	10.2	-	10.0
July 26, 1972	D	10.0	10.9	12.6	12.8	12.4	12.0	11.9	11.9
July 28, 1972	D	10.0	-	11.5	-	-	11.2	-	-
July 29, 1972	D	12.2	11.0	18.0	14.3	14.0	13.0	12.4	12.3
July 29, 1972	MC	9.8	10.2	12.0	11.5	11.4	11.2	-	11.0
July 30, 1972	D	12.5	18.3	17.0	17.0	16.0	15.0	14.0	13.5
Aug 8, 1972	MC	10.5	14.5	12.3	12.3	12.0	11.8	11.8	11.8
Aug 9, 1972	D	10.3	12.4	17.2	16.2	15.1	14.3	13.2	13.2
Aug 10, 1972	IF	10.5	12.3	17.3	16.0	14.9	14.1	13.2	13.3
Aug 11, 1972	IF	10.1	11.3	17.4	16.0	15.2	14.2	13.1	13.1
Sept 6, 1972	MC	8.2	9.1	11.9	12.1	12.1	12.4	12.5	12.5
Sept 8, 1972	D	10.0	12.2	11.7	11.9	11.9	12.2	12.2	12.6
Sept 12, 1972	D	10.0	12.3	9.5	9.5	9.5	9.3	9.2	-
Sept 15, 1972	D	13.0	12.2	10.0	10.0	10.2	9.8	-	-
Sept 19, 1972	D	10.0	9.2	10.1	10.0	9.8	9.7	9.3	-
Sept 22, 1972	D	7.0	3.8	5.5	5.5	6.0	6.5	-	-

TABLE 3 (Continued)

TEMPERATURES IN DEGREES CENTIGRADE

Date	Location	Water T	Air T	Sediment Surf T	1cm	2cm	3cm	4cm	5cm
Sept 25, 1972	MC	10.3	8.0	12.0	10.5	10.2	10.0	10.0	10.0
Oct 5, 1972	IF	7.3	-0.5	2.5	3.0	3.0	3.5	4.0	-
Oct 6, 1972	MC	7.0	6.0	7.5	7.5	7.8	8.0	8.0	8.2
Oct 7, 1972	IF	7.0	-1.0	1.0	2.0	2.1	2.1	2.4	2.6
Nov 4, 1972	D	2.0	7.0	2.0	1.0	1.0	1.2	1.2	2.0
Nov 5, 1972	MC	1.7	1.5	1.6	0.8	1.1	1.2	1.4	1.6
Dec 5, 1972	MC	0.5	-3.0	-1.2	-0.8	-0.2	0.0	0.2	1.2
Dec 7, 1972	D	2.0	-0.5	-0.5	-0.3	-0.3	-0.2	0.0	0.0
Jan 3, 1973	MC	1.9	-0.5	-0.5	-0.4	-0.3	-0.3	-0.3	-0.4
Jan 4. 1973	IF	2.0	0.0	0.0	0.1	0.1	0.2	0.3	0.3
Feb 4, 1973	D	2.1	-3.0	-1.1	-1.0	-1.0	-0.7	-0.5	0.1
Mar 7, 1973	D	2.0	1.5	2.0	2.1	2.4	2.5	2.5	2.5
Mar 8, 1973	MC	1.6	2.5	-	-	-	-	-	-
Mar 9, 1973	MC	2.0	2.2	3.2	3.2	3.2	3.2	3.2	3.2
Mar 10, 1973	OV	1.6	1.8	4.9	4.0	3.8	3.2	3.0	2.9
Apr 5, 1973	IF	3.2	5.0	4.0	4.0	4.0	4.0	4.0	4.0
May 4, 1973	IF	6.0	1.8	2.2	2.5	2.0	2.0	2.0	2.0
June 3, 1973	IF	15.4	12.2	18.8	18.0	17.8	16.8	16.2	15.5
June 4, 1973	IF	15.6	14.2	19.2	19.9	18.7	18.2	17.0	16.6
July 1, 1973	IF	13.6	15.0	20.0	19.5	19.0	18.5	18.0	18.0
July 2, 1973	IF	11.2	16.0	17.0	16.8	16.0	15.5	15.0	15.5
July 3, 1973	IF	11.2	15.0	15.0	15.6	15.5	15.2	15.1	15.0

TABLE 3 (Continued)

TEMPERATURES IN DEGREES CENTIGRADE

Date	Location	Water T	Air T	Sediment Surf T	1cm	2cm	3cm	4cm	5cm
July 4, 1973	IF	11.6	15.4	15.6	15.0	15.0	14.8	14.8	14.8
July 14, 1973	IF	13.0	13.2	13.0	13.0	13.0	12.8	12.4	12.2
July 29, 1973	IF	12.0	12.6	12.6	12.4	12.3	12.2	12.2	12.0
July 30, 1973	IF	11.2	15.0	15.0	15.6	15.5	15.2	15.1	15.0
Aug 1, 1973	IF	10.2	13.5	14.0	14.5	14.5	14.0	14.0	14.0
Aug 2, 1973	IF	9.0	17.5	16.2	16.4	16.3	16.0	16.0	16.0
Sept 13, 1973	IF	12.0	9.0	11.0	11.2	11.8	12.0	12.0	12.0
Sept 14, 1973	IF	11.5	10.6	10.0	10.0	10.3	10.7	11.0	11.0
Sept 15, 1973	IF	11.8	10.3	10.5	10.6	10.7	10.9	11.0	11.0
Sept 29, 1973	OV	5.5	6.0	5.0	5.5	6.0	6.3	6.5	6.8
Oct 2, 1973	OV	5.8	10.0	7.0	7.2	7.8	8.0	8.0	8.0
Nov 10, 1973	MC	0.5	-2.0	-1.0	-0.5	0.0	0.5	0.8	1.0
Nov 12, 1973	IF	4.0	-3.5	-	-	-	-	-	-
Dec 7, 1973	IF	-	2.0	1.5	-	-	-	-	2.0
Dec 8, 1973	IF	-	2.0	1.3	-	-	-	-	1.7
Jan 7, 1974	IF	0.0	-3.0	-0.8	-0.2	0.0	0.0	0.0	0.0
Feb 1974	-	-	-	-	-	-	-	-	-
Mar 6. 1974	IF	2.0	1.5	2.0	2.1	2.4	2.5	2.5	2.5
Mar 23, 1974	IF	1.0	3.0	0.0	0.5	0.2	1.0	1.0	-
Mar 24, 1974	IF	3.3	1.2	3.0	2.9	3.0	3.4	3.8	4.0
Mar 25, 1974	IF	2.5	1.0	4.0	4.0	4.0	4.0	4.0	4.0
Mar 26, 1974	IF	3.5	5.5	5.2	4.8	4.5	4.5	4.2	4.0

TABLE 3 (Continued)

TEMPERATURES IN DEGREES CENTIGRADE

Date	Location	Water T	Air T	Sediment Surf T	1cm	2cm	3cm	4cm	5cm
Mar 27, 1974	IF	3.0	1.5	3.5	2.0	2.1	2.5	3.0	3.2
Mar 28, 1974	IF	4.0	2.0	4.0	4.1	4.1	4.1	4.2	4.2
Apr 23, 1974	IF	1.0	3.0	0.0	0.5	1.0	1.5	2.0	2.0
Apr 24, 1974	IF	4.0	4.0	12.0	12.8	13.0	13.5	13.8	14.0
May 21, 1974	IF	7.5	7.0	10.5	11.0	11.0	11.0	11.0	11.0
May 22, 1974	IF	7.0	13.0	14.8	15.0	15.0	14.5	14.0	13.5
June 19, 1974	IF	7.8	14.0	-	-	-	-	-	-
June 20, 1974	IF	7.8	14.0	-	-	-	-	-	-
June 21, 1974	IF	8.0	12.0	-	-	-	-	-	-
June 22, 1974	IF	8.0	13.3	-	-	-	-	-	-
June 23, 1974	IF	8.0	12.2	-	-	-	-	-	-
June 24, 1974	D	7.6	9.8	7.4	7.4	7.6	7.6	7.6	7.6
June 24, 1974	IF	8.0	17.0	-	-	-	-	-	-
June 26, 1974	IF	8.1	15.3	-	-	-	-	-	-
July 2, 1974	IF	8.8	10.7	-	-	-	-	-	-
July 3, 1974	IF	8.0	12.0	-	-	-	-	-	-
July 4, 1974	IF	7.8	12.0	-	-	-	-	-	-
July 5, 1974	IF	10.0	13.0	-	-	-	-	-	-
July 6, 1974	IF	8.0	16.0	-	-	-	-	-	-
July 7, 1974	IF	8.0	13.0	-	-	-	-	-	-
July 16, 1974	IF	6.1	12.2	-	-	-	-	-	-
July 18, 1974	IF	6.2	12.0	-	-	-	-	-	-

TABLE 3 (Continued)

TEMPERATURES IN DEGREES CENTIGRADE

Date	Location	Water T	Air T	Sediment Surf T	1cm	2cm	3cm	4cm	5cm
July 19, 1974	IF	6.0	11.0	-	-	-	-	-	-
July 20, 1974	IF	6.0	11.3	-	-	-	-	-	-
July 21, 1974	IF	6.0	11.6	-	-	-	-	-	-
July 22, 1974	IF	6.0	10.0	-	-	-	-	-	-
July 23, 1974	IF	6.0	11.4	-	-	-	-	-	-
July 23, 1974	D	8.2	11.0	8.6	8.4	8.4	8.2	8.2	8.2
July 24, 1974	IF	6.0	13.7	-	-	-	-	-	-
July 25, 1974	IF	6.0	12.2	-	-	-	-	-	-
July 31, 1974	IF	7.5	11.5	-	-	-	-	-	-
Aug 2, 1974	D	7.0	11.0	-	-	-	-	-	-
Aug 16, 1974	D	9.8	6.0	-	-	-	-	-	-
Aug 16, 1974	IF	9.8	6.1	-	-	-	-	-	-
Aug 17, 1974	IF	7.3	7.2	-	-	-	-	-	-
Aug 17, 1974	D	9.8	6.0	-	-	-	-	-	-
Aug 18, 1974	D	9.8	6.0	-	-	-	-	-	-
Aug 18, 1974	IF	8.2	7.7	-	-	-	-	-	-
Aug 19, 1974	IF	7.9	6.9	-	-	-	-	-	-
Aug 20, 1974	IF	10.0	10.3	-	-	-	-	-	-
Sept 15, 1974	IF	9.0	11.0	-	-	-	-	-	-
Oct 31, 1974	D	6.0	4.5	8.0	-	-	-	-	-
Nov 29, 1974	D	3.8	1.5	2.9	-	-	-	-	-
Aug 24, 1972	GB*	13.0	-	12.2	12.2	12.0	11.5	11.5	11.3

TABLE 3 (Continued)

TEMPERATURES IN DEGREES CENTIGRADE

Date	Location	Water T	Air T	Sediment Surf T	1cm	2cm	3cm	4cm	5cm
Sept 25, 1972	GB*	10.3	8.0	12.0	10.5	10.2	10.0	10.0	10.0
Jan 21, 1973	GB*	-1.5	-8.3	-7.8	-4.0	-2.0	-1.8	-1.5	-
Nov 9, 1973	GB*	6.5	-0.5	0.5	1.3	2.0	2.6	3.0	3.6

D = Dayville

MC = Mineral Creek

OV = Old Valdez

IF = Island Flats

GB*= Galena Bay; outside of Port Valdez

TABLE 4

MEAN MONTHLY WATER AND AIR TEMPERATURES IN DEGREES CENTIGRADE OF SAMPLES FROM THE PORT VALDEZ AREA. POOLED TEMPERATURES FROM DAYVILLE FLATS, MINERAL CREEK AND ISLAND FLATS (SEE TABLE 3 FOR ALL TEMPERATURE MEASUREMENTS)

Date	Water T	Air T	Surface	1cm	2cm	3cm	4cm	5cm
May 16, 1972	7.6	6.2	-	-	-	-	-	-
June 19, 1972	11.2	12.8	14.0	13.0	12.8	12.0	11.8	11.6
July 21, 1972	10.8	13.7	14.6	14.2	13.4	12.6	12.5	11.7
Aug 10, 1972	10.4	12.6	16.1	15.1	14.3	13.6	12.8	12.9
Sept 15, 1972	9.8	9.5	10.1	9.9	10.0	10.0	10.6	11.7
Oct 6, 1972	7.1	1.5	3.7	4.2	4.3	4.5	4.8	5.4
Nov 4, 1972	1.9	4.3	1.8	0.9	1.1	1.2	1.3	1.8
Dec 6, 1972	1.3	-1.8	-0.9	-0.6	-0.3	-0.1	0.1	0.6
Jan 4, 1973	2.0	-0.3	-0.3	-0.2	-0.2	-0.1	0.0	0.0
Feb 4, 1973	2.1	-3.0	-1.1	-1.0	-1.0	-0.7	-0.5	0.1
Mar 9, 1973	1.8	2.0	3.4	3.1	3.1	3.0	2.9	2.9
Apr 5, 1973	3.2	5.0	4.0	4.0	4.0	4.0	4.0	4.0
May 4, 1973	6.0	1.8	2.2	2.5	2.0	2.0	2.0	2.0
June 4, 1973	15.5	13.2	19.0	19.0	18.3	17.5	16.6	16.1
July 12, 1973	12.0	14.6	15.5	15.4	15.2	14.9	14.7	14.6
Aug 2, 1973	9.6	15.5	15.1	15.5	15.4	15.0	15.0	15.0
Sept 18, 1973	10.2	9.0	9.1	9.3	9.7	10.0	10.1	10.2
Oct 2, 1973	5.8	10.0	7.0	7.2	7.8	8.0	8.0	8.0
Nov 11, 1973	2.25	-2.75	-1.0	-0.5	0.0	0.5	0.8	1.0
Dec 8, 1973	-	2.0	1.4	-	-	-	-	1.9

TABLE 4 (Continued)

MEAN MONTHLY WATER AND AIR TEMPERATURES IN DEGREES CENTIGRADE

Date	Water T	Air T	Surface	1cm	2cm	3cm	4cm	5cm
Jan 7, 1974	0.0	-3.0	-0.8	-0.2	0.0	0.0	0.0	0.0
Feb 14, 1974	-	-	-	-	-	-	-	-
Mar 23, 1974	2.8	2.2	3.1	2.9	2.9	3.1	3.2	3.7
Apr 24, 1974	2.5	3.5	6.0	6.7	7.0	7.5	7.9	8.0
May 22, 1974	7.3	10.0	12.7	13.0	13.0	12.8	12.5	12.3
June 24, 1974	7.9	13.5	7.4	7.4	7.6	7.6	7.6	7.6
July 16, 1974	7.1	12.0	8.6	8.4	8.4	8.2	8.2	8.2
Aug 16, 1974	8.8	7.5	-	-	-	-	-	-
Sept 15, 1974	9.0	11.0	-	-	-	-	-	-
Oct 31, 1974	6.0	4.5	8.0	-	-	-	-	-
Nov 29, 1974	3.8	1.5	2.9	-	-	-	-	-

TABLE 5

SALINITY OF SURFACE WATER AND INTERSTITIAL WATER OF SEDIMENTS IN PORT VALDEZ. SAMPLES TAKEN AT EITHER ISLAND FLATS OR DAYVILLE.

Date	Surface Water Salinity	Salinity of Interstitial water (Sediment Depths)			
		1 cm	2 cm	3 cm	4 cm
Jan 6, 1973	-	29.5	29.6	35.2	33.1
Mar 7, 1973	12.8	-	35.4	-	-
Apr 4, 1973	1.6	27.3	28.3	-	-
May 5, 1973	13.0	27.9	28.5	-	-
June 4, 1973	-	29.2	22.6	31.7	-
July 7, 1973	20.7	24.1	32.8	22.0	-
Aug 1, 1973	2.1	19.0	19.5	19.2	-
Sept 15, 1973	18.6	-	22.6	22.0	-
Nov 10, 1973	28.1	-	-	21.1	-
Jan 7, 1974	30.5	-	-	-	-
Mar 25, 1974	30.0	36.2	36.7	39.0	-
Apr 24, 1974	20.0	32.8	34.5	35.8	-
May 24, 1974	12.0	34.0	32.1	30.6	-
June 24, 1974	1.7	16.0	18.6	11.8	-
July 4, 1974	0.3	-	-	-	-
July 20, 1974	8.9	-	-	-	-
Aug 19, 1974	6.9	-	-	-	-
Sept 15, 1974	13.8	18.0	-	-	-

TABLE 6

SALINITY OF TIDAL WATERS IN PORT VALDEZ, ALASKA[a]

Date	Location	Surface Water	Water Depth in Meters 0.1	0.5	1.0	1.5	2.0	3.0	Bottom
Oct 13, 1974	D	1.6	6.2	24.0[b]	25.3[c]	-	-	-	27.3[d]
Oct 26, 1974	D	1.2	1.5	-	27.7[c]	-	-	-	28.0 (2.1 m)
	MC	3.3	-	-	24.0[c]	-	-	-	24.7 (1.8 m)
Nov 1, 1974	D	28.2	-	28.2	28.9	-	29.4	-	30.0 (2.4 m)
	MC	26.0	-	26.1	26.1	-	27.2	-	29.6 (2.5 m)
Nov 7, 1974	D	28.6	-	30.1	30.4	-	-	-	31.0 (1.5 m)
	MC	24.0	-	27.0	27.7	-	-	-	-
Nov 15, 1974	D	-	-	28.8	28.9	-	29.4	29.5	-
Nov 22, 1974	D	29.6	-	29.8	29.9	-	-	-	31.1 (1.9 m)
	MC	29.9	-	30.1	30.1	-	-	-	30.3 (2.0 m)
Nov 29, 1974	D	23.9	-	29.8	30.2	-	-	-	30.3 (2.0 m)
	MC	23.8	-	26.1	27.9	-	30.6	-	30.6 (2.2 m)
Dec 10, 1974	D	31.3	-	31.7	31.7	-	31.9	31.9	31.9 (4.0 m)
	M	29.8	-	29.7	29.9	-	31.0	31.1	31.3 (3.3 m)
Mar 10, 1975	D	33.5	-	33.7	33.8	-	33.8	-	-
	MC	32.6	-	32.9	33.3	-	33.4	-	33.5 (3.0 m)
Apr 6, 1975	D	31.6	-	33.1	33.2	-	33.5	-	33.5 (2.5 m)
	MC	30.9	-	32.4	32.6	-	33.0	-	33.0 (2.4 m)
Apr 18, 1975	D	7.0	-	32.0	32.6	-	-	-	32.8 (1.8 m)
	MC	15.2	-	31.9	32.6	-	-	-	32.8 (1.5 m)

TABLE 6 (Continued)

SALINITY OF TIDAL WATERS IN PORT VALDEZ, ALASKA[a]

Date	Location	Surface Water	Water Depth in Meters						
			0.1	0.5	1.0	1.5	2.0	3.0	Bottom
Apr 24, 1975	D	30.5	-	31.4	31.8	-	32.1	-	32.5 (2.2 m)
	MC	26.8	-	29.9	31.8	-	-	-	31.8 (1.3 m)
Apr 30, 1975	D	7.0	-	30.3	30.8	-	31.8	-	32.1 (2.6 m)
	MC	19.5	-	31.7	32.0	-	32.2	-	32.2 (2.5 m)
May 6, 1975	D	26.7	-	30.0	30.6	-	30.3	-	30.4 (2.2 m)
	MC	7.7	-	29.1	29.7	-	30.0	-	31.3 (2.3 m)
May 23, 1975	MC	10.4	-	18±1	25.8	-	27.4	-	27.5 (3.0 m)
	D	13.8	-	21.3±5	24.6	28.2	28.5	-	28.9 (2.8 m)
May 30, 1975	D	1.9	-	2.6	20.0	22.5	-	-	22.5 (1.9 m)
	MC	19.3	-	-	19.2	-	21.0	-	- (2.1 m)
Jun 8, 1975	D	0.6	-	1.2	12.6	14.9	18.9	-	25.0 (2.8 m)
	MC	7.1	-	7.6	8.5	12.7	18.1	-	22.8 (2.8 m)
Jun 17, 1975	D	0.1	-	2.1	10.8	19.2	23.7	-	24.5 (2.4 m)
	MC	7.9	-	11.7	12.6	14.2	18.5	-	24.0 (2.5 m)
Jun 25, 1975	MC	11.4	-	11.1	12.0	-	21.6	28.2	- (3.1 m)
	D	6.4	-	5.9	6.4	-	8.8	-	9.0 (2.9 m)
Jul 3, 1975	D	0.2	-	0.0	1.6	8.4	-	-	9.1 (2 m)
	MC	1.2	-	1.4	1.5	17.7	-	-	21.4 (1.8 m)
Jul 9, 1975	D	1.0	-	1.2	1.4	1.9	3.2	4.5	- (3.1 m)
	MC	4.9	-	3.4	4.4	6.1	24.1	28.3	- (3.5 m)

TABLE 6 (Continued)

SALINITY OF TIDAL WATERS IN PORT VALDEZ, ALASKA[a]

Date	Location	Surface Water	0.1	0.5	Water Depth in Meters 1.0	1.5	2.0	3.0	Bottom
Jul 16, 1975	D	-	-	0.4	1.4	13.6	25.2	~27.2	27.2 (3.0 m)
	MC	-	-	2.2	2.3	2.2	2.5	~20.0	20.4 (3.0 m)
Jul 31, 1975	D	3.5	-	0.6	1.5	~3	8.5	~22.5	- (2.8 m)
	MC	2.8	-	2.7	2.7	2.9	22.0	25.0	- (3.2 m)

[a] Data supplied by George Perkins, National Marine Fishery Service. All salinity data in °/₀₀.

[b] = 0-0.6 m

[c] = 0.6-1.2 m

[d] = Depth not recorded

D = Dayville

MC = Mineral Creek

The results of Fe and Mn analyses on interstitial water samples squeezed from various sections of a limited number of sediment cores are included in Table 7. It would seem that there are no significant vertical trends in the Fe concentrations. This suggests that the physicochemical conditions (temperature, pH, and Eh principally) that control the solubility of Fe are similar from a few centimeters below the tidal flat surface to about 16 cm depth, and that the content of Fe in the solid phase throughout the subsurface sediment section is quite homogenous. However, in case of Mn analyses conflicting data have been obtained; data from four cores show a net increase while those from another two cores indicate an overall decrease in Mn toward the core tops. On the basis of the limited data available, it would seem that there is postdepositional dissolution and upward migration of Mn from the subsurface reduced layers. However, there is probably very little oxidative precipitation of this dissolved Mn near or at the sediment top. As such, the bulk of the dissolved Mn is apparently being discharged into the overlying waters at the sediment-water interface.

The pH of all sediment core sections was quite similar; to a depth of 16 cm from the top the pH varied irregularly from 7.2 to 7.4.

Attempts to assess, via geochemical means, the oxic and anoxic anaerobic state of the surface and subsurface sedimentary regime of Island Flats met with some success. It would seem that except for those areas over which decaying marine algae existed, the surficial portions (0 to 3 cm) of the tidal flat sediments were well oxygenated and are, therefore, considered oxic. The concentrations of dissolved oxygen in interstitial waters of these surficial sediments varied from 40 to 55 μg atom/ℓ. However, below the 3 cm level from the top, the concentrations of dissolved oxygen in the sediments were either zero or less than the detectable amounts. This suggests that the subsurface sedimentary regime in the tidal flats is essentially anoxic. Additional studies on H_2S content in sediments support this conclusion. The concentrations of dissolved H_2S in interstitial waters of tidal flat sediments were not the same everywhere. In areas where decaying marine algae were abundant, especially in the tidal flat regime behind Ammunition and adjacent islands (Figure 2), dissolved as well as

TABLE 7

IRON AND MANGANESE CONCENTRATIONS IN SEDIMENT INTERSTITIAL WATERS OF TIDAL FLATS, PORT VALDEZ AREA.

Area and Sample No.	Core Length (in cm)	Fe ppm	Mn ppm
Island Flats No. 1	0-4	0.1	1.0
	4-8	0.2	0.5
	8-12	0.1	0.3
	12-16	0.1	0.2
Island Flats No. 2	0-4	0.3	0.5
	4-8	0.1	1.0
	8-12	0.1	1.4
	12-16	0.2	2.3
	16-20	0.2	2.5
Island Flats No. 3	0-4	0.1	0.2
	8-12	0.2	0.6
Island Flats (H_2S-rich)	0-2	0.3	0.6
Mineral Creek No. 1	0-4	0.3	0.6
	4.3	0.1	0.1
Mineral Creek No. 2	0-4	0.1	1.3
	4-8	0.1	0.2
Dayville Flats	0-1	-	6.6
	1-2	-	2.0
	3-4	-	0.2
	8-12	3.7	6.4
	12-16	3.9	2.2

precipitated H_2S were encountered in profusion both in the surface and subsurface sediments. In the tidal-flat regions free of decaying marine algae, dissolved and precipitated sulfide were not detected in surface and subsurface sediments. No H_2S was found in the surficial sediments (0-3 cm) at the *Macoma balthica* habitat (Figure 2 and Section XI). The presence of small amounts of precipitated sulfide in the subsurface sediments (below 3 cm from the top) was quite apparent but not dissolved H_2S.

The oxic-anoxic status of surface and subsurface sediments in some tidal flat areas is further manifested by vertical changes in sediment colours and the distributional patterns of major meiofaunal communities (Section VI) and *Macoma balthica* populations (Section XI). Along vertical sections of the tidal flat deposits at the 0.3 m tidal height, situated north of Ammunition Island (Figure 2), there is an upper 2 to 3 cm lighter grey sediment layer (oxic and densely populated with *M. balthica*), which is sharply demarcated from a subsurface greyish black layer (anoxic and devoid of any *M. balthica*). At the mid-tide level of the tidal flat, which is south of Ammunition Island, the presence of about 98% of the major meiofaunal groups is restricted to the upper 3 cm (see Section VI). It is believed that the presence of an anoxic environment in the subsurface delimits the distribution of the organisms predominantly to the surficial sediments.

The typical absence of dissolved H_2S and precipitated sulfide in subsurface sediments of Island Flats, at the mid-tide level (0.0 m tide mark), was contrary to our expectation, in view of the fact that there is an abundant potential source of sulfur in the area and there is also a reducing sub-surface environment. Marine algae, some marsh plants and terrestrial plant debris, and meiofauna are observed on the above tidal flats. It may be expected that the remains of these plants and animals after death would become incorporated into the sediments, and as a result of bacterial decay would give forth H_2S. In addition to the dead organic residue it would seem that the presence of adequate amounts of sulfate — associated with sediment interstitial waters — would also be a ready source of sulfur for H_2S generation within the subsurface anaerobic sediment regime. However, it now appears that the remains of these organisms are either very quickly oxidized on the tidal flat surface or are winnowed out swiftly from the tidal flat regime by the ebb tide. Further, the possibility of significant amounts of colloidal organic residues being held by the fine mineral particles of the tidal flat muds would seem quite improbable. Admittedly, the tidal flat sediments at the mid-tide region are essentially muddy, and therefore are very likely to be constituted predominantly of layered silicates with possible high capacity to fix organics in their structures. However, detailed clay mineral studies — to be discussed later — indicate that the type of layered silicates present in the tidal flat sediments of Port Valdez probably would not sequester significant amounts of organics. Thus, it is believed that very little particulate or colloidal organic matters become available in the subsurface sediments for anaerobic bacterial degradation. Most likely an abundance of H_2S could be generated, provided the organic residues were to become preserved in the subsurface sediments, because colonies of bacteria that can produce H_2S from an organic source have been found to occur in the tidal-flat sediments (see Section IX; Norrell and Johnston, 1975[20]). The lack of accumulation of organic matter in the Island Flat deposits is well exemplified by the notably low content of organic carbon in almost all sediments of the flats (Tables 8 and 9). The presence of very low amounts of biogenic material in the sediments is also strongly supported by the bacterial studies conducted by Norrell and Johnston (1975)[20]. The lack of H_2S in the subsurface anoxic sediments at the mid-tide site, in the presence of adequate amounts of sulfate in interstitial waters, may be attributable to the general paucity of sulfate-reducing bacteria in those sediments (Section IX; Norrell and Johnston, 1975)[20] and to the paucity of organic matter present.

The lower tidal flats (i.e., the entire intertidal regime beyond the mid-tide strip marineward) constitutes a distinct depositional subfacies and is delineated as SUBFACIES III in Figure 2. It is distinguished from the tidal flat areas mentioned earlier by the predominance of sandy deposits (sample numbers 15 to 21, Table 1) and relatively small amounts of gravel, silt and clay. Presence of macrofauna was not apparent here.

TABLE 8

ORGANIC CARBON PERCENTS (BY DRY WT.) IN CARBONATE-FREE SEDIMENT CORE SAMPLES ON TIDAL FLATS OF PORT VALDEZ FOR SAMPLES TAKEN SUMMER OF 1973

Location	Tide Ht.	Core Depth (cm)	Carbon wt.%
Island Flats (W)	0	1	0.298
		2	0.258
		3	0.215
		4	0.226
		5	0.230
		6	0.192
		7	0.179
		8	0.184
Island Flats (E)	0	1	0.460
		2	0.463
		3	0.451
		4	0.414
		5	0.450
		6	0.449
Dayville	-1.0	1	0.320
		2	0.240
		3	0.218
		4	0.319
		5	0.246
		6	0.267
		7	0.228
Dayville	-0.5	1	0.349
		2	0.331
		3	0.353
		4	0.262
		5	0.277
		6	0.304
		7	0.309
		8	0.329
		9	0.423
		10	0.275
		11	0.317
Dayville	0	1	0.308
		2	0.238
		3	0.268
		4	0.290
		5	0.296
		6	0.298

TABLE 8 (Continued)

ORGANIC CARBON PERCENTS

Location	Tide Ht.	Core Depth (cm)	Carbon wt.%
Dayville (cont.)	0	7	0.268
		8	0.244
		9	0.251
		10	0.266
		11	0.263
		12	0.284
		13	0.280
		14	0.330
Dayville	0	1	0.322
		2	0.294
		3	0.303
		4	0.348
		5	0.316
		6	0.329
		7	0.319
		8	0.294
Old Valdez	0	1	0.609
		2	0.958
		3	0.441
		4	0.308
		5	0.368
Mineral Creek	-1.0	1	0.354
		2	0.319
		3	0.279
		4	0.254
		5	0.258
		6	0.321
		7	0.323
Mineral Creek	0	1	0.701
		2	0.369
		3	0.336
		4	0.297
		5	0.275
		6	0.259
		7	0.330
Mineral Creek	+2.2	1	0.378
		2	0.354
		3	0.316

TABLE 8 (Continued)

ORGANIC CARBON PERCENTS

Location	Tide Ht.	Core Depth (cm)	Carbon wt.%
Mineral Creek	+2.2	4	0.311
		5	0.293
		6	0.280
		7	0.256
Millard Creek (Galena Bay)	0	1	0.800
		2	1.231
		3	0.370
		4	0.419
		5	0.403
		6	0.338
		7	0.394
		8	0.333
		9	1.002
		10	0.258

TABLE 9

CARBONATE, ORGANIC CARBON, AND TOTAL CARBON CONTENTS IN BASELINE SEDIMENTS OF ISLAND FLATS TAKEN IN THE WINTER OF 1973. ALL PERCENTAGES ARE ON GRAVEL-FREE, DRY WEIGHT BASIS.

Sample No.	$CO_3^=$ %	Org. C %	Total C %[a]
VLDZ10/73-1[b]	0.76	0.268	0.420
VLDZ10/73-2	1.02	0.060	0.300
VLDZ10/73-7	1.64	0.070	0.398
VLDZ10/73-8	1.01	0.023	0.225
VLDZ10/73-9	1.90	0.105	0.485

[a] Organic plus inorganic carbon content.

[b] See Table 12 for additional data for these samples.

It would seem that because of the more severe tidal current agitation, relatively more of the silt and clay size particles are winnowed out of this zone, and dense settlement of macrobenthos is precluded.

Lying immediately seaward of Ammunition Island on the lateral flanks are intertidal sediments that are generally gravelly sand or sandy gravels (Figure 2). These coarse sediments are believed to be old tidal channel lag deposits, originally laid down under high energy conditions. The presence of these deposits outside the channel beds has apparently resulted from lateral migration of tidal channels — a phenomenon quite common to many tidal flat areas of the world. Because the gravels constitute a suitable anchoring device, an abundance of the bivalve *Mytilus edulis* was observed to colonize these coarse deposits.

North of the chain of hillocks (Figure 2) most of the tidal flat environment is dominated by tranquil conditions of sedimentation. This situation has resulted primarily because of relatively less current agitation and turbulence, the hillocks acting somewhat as a buffer to the effects of direct tidal action. Under the relatively tranquil environment the deposition of muddy sediments is favored.

There are, however, a few exceptional environments within the above tranquil area where turbulence prevails because of local intense action of tidal flow and ebb. One of these environments is a tidal channel (Figure 2) where fine particles are winnowed out, leaving a residual channel deposit consisting of a poorly sorted complex of broken shells (mostly of reworked *Macoma balthica* and small *Mytilus edulis*), gravels, and coarse sands. The extensive tidal flat behind the chain of hillocks (Figure 2) is criss-crossed by a network of highly meandering tidal channels. Some of these channels are in fact marineward extensions of freshwater streams arising from the high mountains north of the supratidal region. The upper reaches of these channels may be as deep as 0.9 to 1.2 m and 0.9 to 1.8 m wide, but in the lower reaches the channels are relatively wider (3 to 4 m) and invariably less than 0.3 m deep. Low mounds of coarse debris are observed in some places at a tidal height of 1 m in the vicinity of these tidal channels. These sediments are poor to very poorly sorted, are constituted predominantly of medium to fine sands with subordinate amounts of fine gravels, silts, and clay, and have fine skewed and leptokurtic size distributions (Table 2, sample numbers 22 to 28). As discussed earlier, these elevated areas of coarse debris are presumed to be old tidal channel sediments, stranded where they are now as residual deposits following lateral migration of earlier channels. Subsequent to the channel migration, deposition of muddy particles have been favored in these areas. As a consequence, the original coarse channel deposits have come to have additional mud. The silty-clayey sands of these areas appear to afford an ideal substratum for the establishment of dense groups of the bivalve *Macoma balthica*, for in no other place on the tidal flats are these clams found in such abundance. In Figure 2 the *M. balthica* habitat is delineated as SUBFACIES IV.

Significant lateral changes in faunal facies are noticed within the intertidal areas of the Island Flats. Toward the landward margin, where spread of tidal water is limited, growth of a dense saline marsh vegetation is promoted. However, in tranquil regions over muddy deposits — SUBFACIES V, Figure 2 — the establishment of the chlorophytes *Monostroma* and *Ulva* is favored, whereas on rocky substratum around the high tide mark the phaeophyte *Fucus* is generally supported. There was only one spot in the entire Island Flats area (i.e., in the lower reaches of a tidal channel) where a few stalks of the eelgrass *Zostera* were seen growing.

Dayville Flats

The Dayville Flats (Figure 1) are directly exposed to tidal current action. The progressive changes observed in the lithofacies from the upper to the lower reaches of the flats are largely a function of the sediment source. Progressively marineward from the foot of the high mountains, the sediments grade into finer particles. Nearer the foot of the mountains there is an abundance of stray gravels intercalated with mud. However, at the mid-tide level where meiofaunal sampling was accomplished (Section VI), the sediments consist of poorly to very poorly sorted plastic, dark grey muds (mean size around fine silt or coarse clay; 2 to 16 μ), that have fine skewed and leptokurtic size distributions (Table 2). Such a texture is similar to the intertidal sediments situated at the mid-tide level at Island Flats. As elsewhere, dense beds of the mussel *Mytilus edulis* are found to grow favorably only on gravel pavements.

Mineral Creek Flats

This area (Figure 1) was not investigated as intensively as the other two. The tidal flats have developed on the lower reaches of fluvial outwashes of the Mineral Creek — a significant melt-water stream. The tidal-flat sediments are invariably constituted of very poorly sorted coarse to medium sands (4 μ to 2.5 mm) with subordinate muds and little amounts of gravels; with fine skewed and leptokurtic size distributions (Table 2). Strictly speaking, Mineral Creek Flats should be classed under tidal sand flats rather than mud flats. In the lower reaches as well as the subtidal shallow-marine areas an abundance of healthy stalks of the eelgrass *Zostera* are noticed. Mussels are abundant over most of this area.

LITHOLOGICAL AND CHEMICAL CHARACTERISTICS OF SEDIMENTS

Sediment Texture

Results of the grain-size analyses on tidal flat sediments of the Island Flats, Dayville Flats, and Mineral Creek Flats are included in Tables 1 and 2. The lateral variations in surficial lithology of the Island Flats are graphically represented in Figure 2, and have been elaborated upon in the previous section on "Depositional Environments...". No significant vertical variations, either in lithology or structure, were observed to a depth of 16 cm from the top, at the mid-tide region (0.0 m high tide mark) of the flats; the sediments were uniformly muddy with subordinate amounts of sand and traces of gravel.

Clay Mineralogy

Results of the clay mineral analysis on oriented grains of less than 2 mμ size fraction of 9 sediment samples, collected in vicinity of the mid-tide (0.0 high tide mark) of Island Flats, are included in Table 10.

TABLE 10

WEIGHTED PEAK AREA PERCENTAGES OF CLAY MINERALS IN TIDAL FLAT SEDIMENTS, PORT VALDEZ

Sample	Illite	Chlorite
VLDZ3/74-1	45	55
VLDZ3/74-2	40	60
VLDZ3/74-3	43	57
VLDZ74-4	44	56
VLDZ74-5	46	54
VLDZ74-10	43	57
VLDZ74-11	43	57
VLDZ74-12	58	42
VLDZ74-14	48	52

The clay mineral assemblages are very similar in all the samples and consist almost entirely of chlorite (42 to 60%; average: 49%), and illite (40 to 58%; average: 46%). Kaolinite and smectite were sought but were not detected. The presence of very sharp X-ray diffractogram peaks of both chlorite and illite basal d reflections for the oriented grains suggest that the atomic lattice of these minerals are very well ordered, and presumably also mean that the minerals are detrital, primary grains which have been subjected to very little chemical weathering. The basal d reflection intensities further suggest that the so-called illites are essentially dioctahednal, aluminion mica (e.g., muscovite). Further insight into the polytype compositions of the minerals are rendered possible by means of detailed X-ray analysis on randomly oriented grains of three of the above nine clay samples (Figure 3). The presence essentially of the 2M polytype mica is inferred from the well-defined (023), (025), and (116) d reflections at 3.74Å, 3.00Å, and 2.80Å d spacings, respectively (Yoder and Eugster, 1955)[21]. Further, the near absence of the very characteristic 3.66Å peak (Figure 3), representing the $(11\bar{2})$ d reflection, suggests the near absence of the 1M and 1Md mica polytypes. Likewise, the plausible occurrence of the IIb polytype chlorite (Hayes, 1970[22]) in the intertidal clays of Tidal Flats, Port Valdez, is inferred from the presence of the fairly well-defined $(20\bar{2})$ and (201) d reflections (Figure 3), which are a manifestations of the characteristic 2.59Å and 2.54Å d spacings, respectively (Bailey and Brown, 1962)[23].

Sediment Chemistry

The concentrations of organic carbon in tidal flat sediments of the three type areas have been cited elsewhere (Feder, 1973[24]; Tables 8 and 9). No systematic vertical variations in the organic carbon contents are evident in any of the sediment cores. In addition, in the three type areas the organic carbon contents are notably low and quite similar. Table 9 includes the concentrations of carbonate, organic carbon, and total carbon in baseline sediment samples. It is clear that in all sediment samples examined, the organic carbon and total carbon values are comparative and quite low.

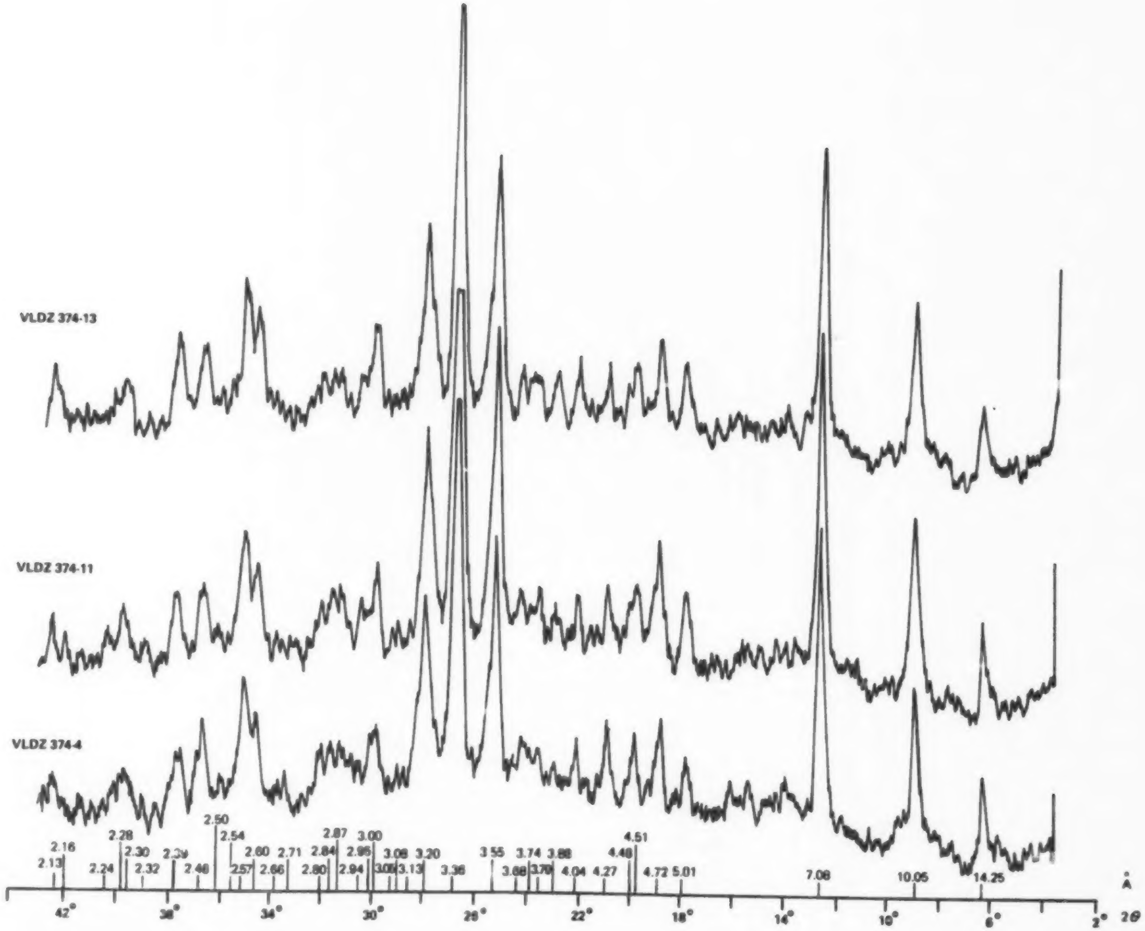

Figure 3. Typical x-ray diffractogram traces of randomly oriented, less than 2 micron fraction of intertidal sediments, Port Valdez.

The baseline chemical data, indicating the semiquantitative analysis of trace elements on surface and subsurface sediments of tidal flats of the three type areas of Port Valdez, are shown in Table 11. Except in case of a few exceptions, relatively higher concentrations of all elements are noted in the subsurface sediments of all cores. Generally, there are relatively smaller concentrations of most elements in the sediments of Mineral Creek Flats, as compared to tidal flat sediments of Dayville and Island Flats.

In Table 12 are shown the baseline concentrations of Cu, Pb, Zn, Ni, and V in four gravel-free gross sediments, as well as in the mud fraction (less than 62 mμ) of nine sediment samples from Island Flats. It is evident that there is no preferential partitioning of heavy metals based on sediment grain size, except as in case of V which appears to be relatively concentrated in the coarser fraction. It is important to note that the baseline sediment sample VLDZ6/73-7 was collected from the immediate vicinity of the standard reference stake established at the beginning of the present study at mid-tide mark. The remaining baseline gravel-free samples, were collected near the mid-tide reference point but further seaward than sediment sample VLDZ6/73-7.

In Table 13 are listed the baseline concentrations of some heavy metals in a selected group of faunal and floral species that thrive on the Island Flats.

The trace metal data in Tables 11 and 12 should be considered as useful baselines to detect any chemical pollution of the tidal flat ecosystem, and the data in Table 13 should be of particular interest in this respect relative to some indicator faunal and floral communities analyzed. The significant differences of Cu and Pb contents between various samples of *Mytilus* tissues are probably a function of the presence of varying amounts of particulate matter in the alimentary canals of the three samples of the bivalve. It is suggested that for meaningful baseline trace element data, analysis should only be made on bivalves that have been previously purged of intestinal contents.

TABLE 11

TRACE ELEMENT CONCENTRATIONS (IN PPM) IN TIDAL FLAT CORE SEDIMENTS, PORT VALDEZ AREA

	Island Flats		Dayville Flats		Mineral Creek	
Element	Core Top/	Core Bottom	Core Top/	Core Bottom	Core Top/	Core Bottom
Cr	220	380	220	260	105	140
Sr	275	300	315	250	280	215
Co	30	30	25	35	10	15
Ni	180	170	130	260	130	120
Sc	40	45	35	50	25	30
Zn	ND	ND	ND	ND	ND	ND
La	ND	ND	ND	ND	ND	ND
Y	35	50	40	45	30	35
Ag	ND	2	ND	ND	ND	ND
Zr	350	350	370	250	140	180
Cu	80	85	85	120	40	50
Cd	ND	ND	ND	ND	ND	ND
Sn	ND	ND	ND	ND	ND	ND
Mo	4	5	6	7	3	4
Be	1	1	1	1	1	1
V	310	320	210	240	230	240
Bi	ND	ND	ND	ND	ND	ND
Pb	30	25	20	25	20	20
B	30	35	20	30	50	35
Nb	15	20	15	20	15	20

NOTE: ND indicates elements sought for but found to be below the limits of detection. The results are semiquantitative, at best. Precision of analysis: ± 50% of the value at 95% confidence level.

TABLE 12

BASELINE CONCENTRATIONS (IN PPM) OF HEAVY METALS IN THE GRAVEL-FREE GROSS SEDIMENTS AND MUD FRACTIONS OF TIDAL FLAT DEPOSITS, ISLAND FLATS, PORT VALDEZ

Sample No.	Sediment Fraction	Cu	Pb	Zn	Ni	V
VLDZ6/73-1	Gravel-free gross	60	34	130	85	290
VLDZ6/73-2	Gravel-free gross	61	36	130	85	280
VLDZ6/73-7[a]	Gravel-free gross	36	29	95	62	225
VLDZ6/73-9	Gravel-free gross	56	33	115	81	265
VLDZ3/74-1	Mud	63	30	122	85	220
VLDZ3/74-2	Mud	63	26	129	89	230
VLDZ3/74-3	Mud	61	30	135	87	230
VLDZ3/74-4	Mud	62	31	139	85	220
VLDZ3/74-5	Mud	66	32	132	88	220
VLDZ3/74-10	Mud	59	23	122	81	230
VLDZ3/74-11	Mud	65	27	131	83	230
VLDZ3/74-12	Mud	63	26	132	83	230
VLDZ3/74-14	Mud	60	30	153	81	230
Average	Gravel-free gross	53	33	117	79	265
Average	Mud	62	28	133	85	227

[a] Sediment sample collected in the immediate vicinity of the reference stake at mid-tide (0.0 m high tide level) horizon of Island Flats.

The rest of the Samples were collected from farther away from the Sample VLDZ6/73-7 but near the mid-tide level.

TABLE 13

BASELINE TRACE ELEMENT DATA ON SOME FAUNAL AND FLORAL TISSUES, ISLAND FLATS, PORT VALDEZ. ALL VALUES ARE ON FREEZE-DRIED WEIGHT BASIS.

Sample	Cu ppm	Pb ppm	Zn ppm	Cd ppm	Ni ppm	Mo ppm	Hg ppm
Mytilus A	3.6	2.4	86	10.0	3	<1	0.3
Mytilus B	2.8	2.4	92	10.0	3	<1	NA[a]
Mytilus C	1.2	1.1	88	10.0	3	<1	NA[a]
Monostroma A	1.4	3.7	11	0.3	2	<1	0.4
Monostroma B	1.2	1.6	6	0.5	1	<1	NA[a]
Monostroma C	1.0	1.6	10	0.5	1	<1	NA[a]
Ulva	6.6	0.4	17	0.7	<1	<1	0.9
Macoma	2.0	1.1	200	0.6	3	1	0.6
Fucus	8.0	0.4	31	0.04	10	<1	0.1

[a] NA: Not analyzed

SECTION V

GENERAL MICROBIOLOGY OF MARINE SEDIMENTS OF PORT VALDEZ, ALASKA

INTRODUCTION

Decomposition and recycling of organic remains is the major role performed by soil and sediment microorganisms. One of the major steps in nutrient recycling is the consumption of microflora by selected micro, meio, and macrofauna. No study of marine sediment productivity and general ecology can be complete without giving consideration to the distribution, abundance and role of resident microorganisms and their interaction with associated fauna. Since virtually nothing is known about the microflora occurring naturally in Port Valdez marine sediments, it was the purpose of this research to isolate the microorganisms present and to gain some insight into their distribution and abundance with respect to particular sites and various depths in the sediment profile.

METHODS

Sediment samples were taken from three mid-tide horizons in the Port Valdez, Alaska area (Section IV, Figure 1) on July 28-29, 1972: Old Valdez (a beach with a persistent percolation of oil from tanks ruptured during the earthquake of 1964), Island Flats, and Mineral Creek. Cores of the sediments were extracted with a sterile plastic cylinder 4.5 cm inside diameter. The sample was placed on a wooden cutting board (sterilized with alcohol) and sections of the sediments cut into desired lengths to correspond to particular depths in the profile. Each section was then placed in a whirlpak bag. The unprocessed samples were stored overnight in a refrigerator and placed in ice chests for transport to Fairbanks.

One gram of each of the twelve sediments was placed in 99 ml of sterile sea water together with glass beads and set on a mechanical shaker for a period of 15 minutes. From this suspension, 1 ml of the solution was taken to make further dilutions as were necessary. Media used were as follows: ZoBell's 2216e Aaronson, (1970)[25] for aerobic bacteria, modified ZoBell's 2216e Aaronson, (1970)[25] for anaerobic bacteria, Glucose-Peptone (Fell and

Van Uden, 1963)[26] for yeasts, Yeast-Extract Glucose Johnson and Sparrow, (1961)[27] and Czapex Dox for filamentous fungi. The Starch-Casein-Actinomycete medium used successfully by Grein and Meyers (1958)[28] was utilized as well as Bacto-Actinomycete Isolation agar. Aged sea water was used in media and dilution blanks. Water was prepared by filtering freshly collected water to remove particulate matter and the water was then stored in the dark in five-gallon carboys. Media were not acidified as many salt water fungi are reported to be inhibited by acidified media as are many marine bacteria. Cyclohexamide and streptomycin were routinely used as fungal and bacterial inhibitors.

One milliliter of the appropriate sediment dilution was placed in petri dishes and cooled but still molten media poured over the sample. Plates were swirled to distribute the sample and incubated at room temperature and in a few instances at 5°C. Each sample from a given depth was plated in triplicate for subsequent use in making plate counts and obtaining organisms for identification. Transfers to tube slants were made from plates containing filamentous fungi and yeasts. After an incubation period of 14 days, the tube cultures were sorted into presumptive species groups.

GasPak anaerobic jars were used for all anaerobic incubations.

RESULTS

The numbers of bacteria per gram varied from site to site as well as with depth in the profile. As shown in Table 14, when incubated at room temperature numbers of aerobic bacteria were highest at the Island Flats site from the surface to 3 cm deep (8.2×10^5/g of sediment). Dilution plates from the Old Valdez sediments incubated at 5°C yielded higher numbers (6.9×10^5/g) than were found on plates incubated at room temperature (2.7×10^5). A general decrease in numbers with increased depth was exhibited with the notable exception at the 16 to 20 cm depth at the Old Valdez site. This was true of plates incubated both at room temperature and 5°C. Anaerobic bacteria were found in greatest numbers at the Mineral Creek site; 1.1×10^5/g.

TABLE 14

NUMBER OF ORGANISMS PER GRAM OF SEDIMENT OBTAINED FROM THREE SITES IN PORT VALDEZ.

Location	Depth (cm)	Number of Organisms per Gram		
		Bacteria	Fungi	Yeasts
ISLAND FLATS				
Aerobic	0-3	820,000	700	1,000
(Room temperature	4-6	490,000	100	6,100
incubation)	7-12	112,000	100	800
Anaerobic	0-3	46,000	-	-
(Room temperature	4-6	15,000	-	-
incubation)	7-12	8,000	-	-
MINERAL CREEK				
Aerobic	0-3	540,000	400	1,400
(Room temperature	4-6	145,000	100	400
incubation)	7-9	232,000	100	1,400
	10-12	140,000	100	1,000
Anaerobic	0-3	109,000	-	-
(Room temperature	4-6	9,000	-	-
incubation)	7-9	11,000	-	-
	10-12	30,000	-	-
OLD VALDEZ				
Aerobic	0-3	270,000	2,800	1,800
(Room temperature	4-9	118,000	3,700	100
incubation)	10-12	75,000	600	4,600
	13-15	68,000	1,100	300
	16-20	180,000	500	2,500
(5°C incubation)	0-3	690,000	1,800	3,500
	4-9	250,000	3,700	4,100
	10-12	235,000	100	1,800
	13-15	62,000	200	600
	16-20	240,000	200	2,800
Anaerobic	0-3	8,000	-	-
(Room temperature	4-9	-	-	-
incubation)	10-12	-	-	-
	13-15	13,000	-	-
	16-20	-	-	-

Numbers of filamentous fungi and yeasts were found to be low and there was a general decrease in numbers with increased depth. The highest numbers of both filamentous fungi and yeasts were obtained from the Old Valdez site, 3700 and 1800/g, respectively. All profiles were checked for the possible presence of anaerobic fungi but none were isolated.

Actinomycetes were not isolated from the Mineral Creek and Island Flats sites and were found rarely and in such small numbers at Old Valdez that no numerical data is included on them in this report. A total of five species were encountered and all occurred at the 4 to 9 cm depth.

Percent density of filamentous fungi and yeasts within sites for the three areas is shown in Table 15. Percent density was calculated according to the following formula:

$$\frac{\text{Number of isolates of a particular species}}{\text{Total isolates}} \text{ X } 100$$

Yeast distribution did not appear to follow a pattern, i.e., V-1 was not isolated from the 0 to 3 cm sample of any of the three sites; V-2 was isolated from the surface to 20 cm deep while V-23 and V-92 were isolated only from 0 to 3 cm samples. Numbers of species of yeasts did not appear to decrease with increased depth and actually increased at the 16 to 20 cm depth in the Old Valdez site. It is interesting to note that no yeasts were isolated from Old Valdez at a depth of 4 to 9 cm, the only cores which yielded Actinomycetes.

Filamentous fungi were somewhat restricted in distribution as to location in the profile and numbers of species decreased with increasing depth. V-47, V-42, V-20 and V-19 were restricted to the upper horizons and V-9, V-71, V-68 were isolated from mid-horizons. While eight species were isolated from the 16 to 20 cm depth at Old Valdez, none were restricted to that depth. V-36, a pycnidial form, made up 52.6% of the total isolates from this depth. At Island Flats, no filamentous fungi were recovered from the 4 to 6 cm depth and the 7 to 12 cm depth yielded only one species.

High density species which are characteristic of terrestrial fungal populations were not found in the Valdez samples. Cultures numbered V-47, 26, 64, 8, 9, 66, 36, 37, were the only species occurring with densities

TABLE 15

PERCENT DENSITY OF FILAMENTOUS FUNGI AND YEASTS WITHIN SITES. THE SYMBOL V = UNIDENTIFIED SPECIES

ISLAND FLATS

Culture No.		Depth (cm) 0-3	4-6	7-12
YEASTS				
V-1		-[a]	71.4	71.4
V-2		11.1	9.5	14.2
V-3		-	2.3	7.1
V-4		-	11.9	-
V-5		-	2.3	3.5
V-11		-	2.3	-
V-54		-	-	3.5
V-56		55.5	-	-
V-61		11.1	-	-
V-92		22.2	-	-
FILAMENTOUS FUNGI				
V-6		3.0	-	-
V-7		9.0	-	-
V-14		3.0	-	-
V-17	*Phialophora* sp.	30.3	-	-
V-55	*Cladosporium* sp.	3.0	-	-
V-57		6.0	-	-
V-66	*Chrysosporium* sp.	3.0	-	-
V-59		3.0	-	-
V-60	*Phialophora* sp.	9.0	-	-
V-20		3.0	-	-
V-8	*Cylindrocarpon* sp.	9.0	-	-
V-62		3.0	-	-
V-75		3.0	-	-
V-79		3.0	-	-
V-21	*Mucor* sp.	3.0	-	-
V-91		3.0	-	-
V-26		-	100.0	-

MINERAL CREEK

Culture No.	Depth (cm) 0-3	4-6	7-9	10-12
YEASTS				
V-2	14.2	5.2	84.6	-
V-3	-	10.5	-	6.2
V-53	-	5.2	-	-
V-54	21.4	73.6	-	3.1
V-65	7.1	-	-	68.7
V-4	-	-	-	6.2
V-5	14.2	5.2	-	3.1

TABLE 15 (Continued)

PERCENT DENSITY OF FILAMENTOUS FUNGI AND YEASTS WITHIN SITES

MINERAL CREEK (cont.)

Culture No.		Depth (cm)			
		0-3	4-6	7-9	10-12
YEASTS					
V-70		-	-	-	3.1
V-73		-	-	-	6.2
V-1		-	-	-	3.1
V-38		-	-	7.6	-
V-25		7.1	-	7.6	-
V-23		14.2	-	-	-
V-34		7.1	-	-	-
V-89		7.1	-	-	-
V-20		7.1	-	-	-
FILAMENTOUS FUNGI					
V-18	*Trichoderma polysporum*	15.7	-	-	-
V-19		10.5	-	-	-
V-20		15.7	-	-	-
V-21		5.2	-	-	-
V-27		5.2	-	-	-
V-29		5.2	-	-	-
V-30		5.2	-	-	-
V-31		5.2	-	-	-
V-33	Sphaeropsidales	5.2	-	-	-
V-42		5.2	-	-	-
V-90		10.5	-	-	-
V-35	*Penicillium* sp.	5.2	-	-	-
V-45		5.2	-	-	-
V-9		-	25.0	50.0	-
V-22	*Penicillium* sp.	-	25.0	-	-
V-32		-	25.0	-	-
V-64	*Penicillium* sp.	-	25.0	-	50.0
V-8	*Cylindrocarpon* sp.	-	-	50.0	-
V-66	*Chrysosporium* sp.	-	-	-	50.0

OLD VALDEZ

Culture No.	Depth (cm)				
	0-3	4-9	10-12	13-15	16-20
YEASTS					
V-25	-	-	-	-	21.2
V-1	-	-	-	-	12.1
V-4	12.5	-	-	-	9.0
V-38	-	-	-	-	3.0
V-2	37.5	-	-	50.0	21.2

TABLE 15 (Continued)

PERCENT DENSITY OF FILAMENTOUS FUNGI AND YEASTS WITHIN SITES

OLD VALDEZ (cont.)

		Depth (cm)				
Culture No.		0-3	4-9	10-12	13-15	16-20
YEASTS						
V-41		-	-	-	-	3.0
V-54		12.5	-	-	-	15.1
V-3		-	-	8.0	-	3.0
V-36		-	-	-	-	6.0
V-61		-	-	8.0	12.5	-
V-87		-	-	-	12.5	-
V-44		-	-	-	12.5	-
V-56		-	-	16.6	-	-
V-58		-	-	8.0	12.5	-
V-86		-	-	58.3	-	-
V-73		12.5	-	-	-	-
V-74		12.5	-	-	-	-
V-78		12.5	-	-	-	-
V-53		-	-	-	-	3.0
FILAMENTOUS FUNGI						
V-18	*Trichoderma polysporum*	5.5	-	-	-	5.2
V-28		-	1.4	-	-	10.5
V-22	*Penicillium* sp.	-	-	-	-	5.2
V-35	*Penicillium* sp.	-	4.3	-	2.9	5.2
V-36	Sphaeropsidales	1.8	-	-	-	52.6
V-8	*Cylindrocarpon* sp.	1.8	-	-	-	5.2
V-10	*Chrysosporium* sp.	5.5	24.6	-	3.1	5.2
V-43		1.8	-	-	6.2	10.5
V-37		-	5.7	47.3	46.8	-
V-39		3.7	4.3	-	3.1	-
V-40		-	1.4	-	3.1	-
V-9		-	-	-	3.1	-
V-42		11.0	-	-	6.2	-
V-27		-	-	-	3.1	-
V-46		7.4	-	-	3.1	-
V-45		-	4.3	-	-	-
V-7		5.5	1.4	-	-	-
V-47	*Phialophora* sp.	5.5	1.4	-	-	-
V-48	*Penicillium* sp.	-	7.2	-	-	-
V-49		-	1.4	-	-	-
V-64	*Penicillium* sp.	7.4	1.4	-	-	-
V-80		-	4.3	-	-	-
V-77		5.5	1.4	-	-	-
V-82		-	1.4	-	-	-
V-66	*Chrysosporium* sp.	1.8	15.9	-	3.1	-

TABLE 15 (Continued)

PERCENT DENSITY OF FILAMENTOUS FUNGI AND YEASTS WITHIN SITES

FILAMENTOUS FUNGI (cont.)		Depth (cm)				
		0-3	4-9	10-12	13-15	16-20
V-69		7.4	11.5	-	-	-
V-63		-	-	5.2	-	-
V-68		-	-	5.2	3.1	-
V-71		-	-	10.5	-	-
V-75		-	-	5.2	-	-
V-81	*Trichoderma viride* var.	-	-	5.2	-	-
V-84	*Trichoderma viride* var.	-	-	15.7	-	-
V-88		-	-	5.2	-	-
V-60		1.8	1.4	-	-	-
V-76		3.7	-	-	-	-
V-6		1.8	-	-	-	-
V-83	Sphaeropsidales	1.8	-	-	-	-
V-19		5.5	-	-	-	-
V-85	*Mucor microsporus*	1.8	-	-	-	-
V-93		1.8	-	-	-	-
V-99		3.7	-	-	-	-
V-44		1.8	-	-	-	-
V-100		1.8	-	-	-	-
V-97		-	1.4	-	-	-
V-62		-	1.4	-	-	-
V-98		-	-	-	3.1	-
V-101		-	-	-	6.2	-

[a] Dash indicates non-occurrence of species at particular depth.

of over 30% and these eight organisms were distributed between three sites and 12 depths.

Tables 16 and 17 illustrate percent density of fungi and yeasts between sites with no regard to depths of occurrence. When microfungal populations were compared in this manner definite differences emerged. Among the 63 species of filamentous fungi isolated, only two, V-8 and V-66 occurred in all three sites. Of the 63 species isolated 46 were restricted to particular sites (see below). The highest density recorded for any one fungal organism was 29.4% for V-47, a *Phialophora* sp. The majority of the organisms occurred in low densities (less than 5%) and tended to be site specific.

A total of 47 species of fungi and 19 yeasts were obtained from the Old Valdez site. Thirty species of fungi and 8 yeasts were unique to that site. Mineral Creek sediments yielded 19 species of fungi; 7 unique to that site and 15 yeasts, 5 of which were not isolated elsewhere. Eighteen species of fungi were isolated from Island Flats, 9 not found elsewhere and 10 species of yeast, 4 of which were not isolated from the other two sites. Yeast species appeared to be more cosmopolitan in distribution as evidenced by V-1, V-2, V-3, V-4 and V-54. V-65 was the only yeast occurring in a high density (29.8%) which was restricted to one site.

It was not within the scope of this preliminary survey to attempt a detailed taxonomic study of the organisms isolated or to try to determine their possible roles in decomposition. Nothing is known about the yeasts isolated in this study other than that they fall into both "red" and "white" color groups. Johnson and Sparrow (1961)[27] report a large number of yeasts and yeast-like fungi have been collected from marine waters or isolated from marine materials of various sorts. Most fall into two categories, ones identified as non-marine species and ones merely identified to genus or to color groups.

Of 41 bacterial isolates, 92.6% proved to be gram negative rods, many somewhat pleomorphic. This concurs with findings reported by Murchalana and Brown (1970)[29] on bacteria obtained from marine water samples.

Mucor microsporus, a *Mucor* sp., two *Trichoderma viride* variants, *Trichoderma polysporum*, four species of Penicillia and species belonging to the genera: *Cladosporium*, *Phialophora*, *Chrysosporium*, *Cylindrocarpon*,

TABLE 16

PERCENT DENSITY OF MICROFUNGI BETWEEN SITES.
THE SYMBOL V = UNIDENTIFIED SPECIES

Culture No.	Name	Island Flats	Mineral Creek	Old Valdez
V-6		2.9	-[a]	.5
V-7		8.8	-	2.0
V-8	*Cylindrocarpon* sp.	8.8	3.7	1.0
V-9		-	7.4	.5
V-10	*Chrysosporium* sp.	-	-	11.4
V-14		2.9	-	-
V-17		2.9	-	-
V-18	*Trichoderma polysporum*	-	11.1	2.0
V-19		-	7.4	1.0
V-20		2.9	11.1	-
V-21	*Mucor* sp.	2.9	3.7	-
V-22	*Penicillium* sp.	-	3.7	.5
V-26		2.9	-	-
V-27		-	3.7	-
V-28		-	-	1.5
V-29		-	3.7	-
V-30		-	3.7	-
V-31		-	3.7	-
V-32		-	3.7	-
V-33	Sphaeropsidales	-	3.7	-
V-35	*Penicillium* sp.	-	3.7	1.0
V-36	Sphaeropsidales	-	-	7.2
V-37		-	-	15.1
V-39		-	-	3.1
V-40		-	-	1.0
V-42		-	3.7	4.1
V-43		-	-	2.6
V-44		-	-	.5
V-45		-	3.7	2.0
V-46		-	-	2.6
V-47	*Phialophora* sp.	29.4	-	2.0
V-48	*Penicillium* sp.	-	-	2.6
V-49		-	-	.5
V-55	*Cladosporium* sp.	2.9	-	-
V-57	*Penicillium* sp.	5.8	-	-
V-59		2.9	-	-
V-60	*Phialophora* sp.	8.8	-	1.0
V-62		2.9	-	.5
V-63		-	-	.5
V-64	*Penicillium* sp.	-	7.4	2.6
V-66	*Chrysosporium* sp.	2.9	3.7	6.7
V-68		-	-	1.0

TABLE 16 (Continued)

PERCENT DENSITY OF MICROFUNGI BETWEEN SITES

Culture No.	Name	Island Flats	Mineral Creek	Old Valdez
V-69		-[a]	-	6.2
V-71		-	-	1.0
V-75		2.9	-	.5
V-76		-	-	1.0
V-77		-	-	2.0
V-79		2.9	-	-
V-80		-	-	1.5
V-81	*Trichoderma viride* var.	-	-	.5
V-82		-	-	.5
V-83		-	-	.5
V-84	*Trichoderma viride* var.	-	-	1.5
V-85	*Mucor microsporus*	-	-	.5
V-88		-	-	.5
V-90		-	7.4	-
V-91		2.9	-	-
V-93		-	-	.5
V-97		-	-	.5
V-98		-	-	.5
V-99		-	-	1.0
V-100		-	-	.5
V-101		-	-	1.0
Total Species		18	19	47

[a] Dashes indicate non-occurrence of species at particular depth.

TABLE 17

PERCENT DENSITY OF YEASTS BETWEEN SITES. THE SYMBOL V = UNIDENTIFIED SPECIES

Culture No.	Island Flats	Mineral Creek	Old Valdez
V-1	63.2	1.2	6.5
V-2	11.2	18.1	22.9
V-3	3.7	5.1	3.2
V-4	6.3	2.5	6.5
V-5	2.5	5.1	-[a]
V-11	1.2	-	-
V-23	-	2.5	-
V-24	-	1.2	-
V-25	-	2.5	11.4
V-36a	-	-	3.2
V-38	-	1.2	1.6
V-41	-	-	1.6
V-44	-	-	1.6
V-53	-	1.2	1.6
V-54	1.2	23.3	9.8
V-56	6.3	-	3.2
V-58	-	-	3.2
V-61	1.2	-	4.9
V-65	-	29.8	-
V-70	-	1.2	-
V-73	-	2.5	1.6
V-74	-	-	1.6
V-78	-	-	1.6
V-86	-	-	11.4
V-87	-	-	1.6
V-89	-	1.2	-
V-92	2.5	-	-

[a] Dashes indicate non-occurrence of species at particular depth.

as well as three pycnidial forms (Sphaeropsidales) make up a part of the microfungal population. Species in the above genera are often isolated from Alaskan soils. Johnson and Sparrow (1961)[27] indicate that species of Penicillia seem to occur in abundance in marine muds and in lesser abundance one may find species of *Aspergillus, Cephalosporium, Trichoderma, Chaetomium, Alternaria, Cladosporium,* and *Rhizopus*. None of these genera is typically marine.

DISCUSSION

Sediment samples were taken from three mid-tide horizons in the Port Valdez area. By means of dilution plating on selective media, the filamentous fungi, bacteria, actinomycetes, and yeasts were obtained for future identification and at the same time information was gathered on numbers of different types of organisms with respect to particular sampling site and to depth in the profile.

Preliminary observations were as follows: Numbers of filamentous fungi and yeasts were low, 100-3700/gram of sediment; 100-6100/gram respectively. Numbers of filamentous fungi decreased rapidly with an increase in depth of sample. On two of the three beaches sampled yeast numbers were lower from the surface to a depth of 3 cm, increased at mid depths and decreased with depth thereafter. Numbers of aerobic bacteria ranged from 6.2×10^5 to 8.2×10^5/g of sediment and in general exhibited a decrease in numbers with increased depth. However, at one sampling site numbers decreased from 10 to 15 cm deep and showed a marked increase from 16 to 20 cm deep. Numbers of anaerobic bacteria ranged from 8×10^3 to 1.1×10^5/g and again decreased in numbers with increased depth.

The sampling site in the area of Old Valdez appears to be the richest in fungal flora both in numbers per gram and variety of species. Forty-seven species of microfungi were isolated from this site as opposed to 19 from the site at Mineral Creek and 18 from Island Flats. Five species of Actinomycetes were recovered from the Old Valdez site and none were recovered from sediments from the other two sites. Aerobic bacteria were most numerous at the Island Flats site (8.2×10^5/g) and anaerobic bacteria were most abundant at Mineral Creek (1.1×10^5/g).

Ninety-two percent of the bacterial isolates subjected to gram staining proved to be gram negative rods.

Taxonomy of the fungi isolated is by no means complete but the known genera do not include any typically marine organisms. Sampling was only carried out once during the summer so no information was obtained on seasonal variations if these sediment populations do indeed exhibit fluctuation in numbers. Since microorganisms were found at all depths sampled, future cores should be taken to greater depths in the profile. When petri dishes were incubated at 5°C rather than at room temperature, some interesting results were obtained and this indicates that future work might well be carried out at temperatures which approach field conditions. The increase in numbers of organisms at the 16 to 20 cm depth at the Old Valdez site should be investigated to determine whether the increase was due to sampling error or to some parameter such as structure or chemistry of that particular sediment related to the continuing presence of oil here.

SECTION VI

SEASONAL OBSERVATIONS OF THE INTERTIDAL MEIOFAUNA

INTRODUCTION

The food web of any marine environment is very complex. Although many examples of portions of such food webs are available from various parts of the world (see Green, 1968[30] for review), most of these food interrelationships are incompletely understood even in areas where such studies have been in progress for many years (Thorson, 1957)[31]. Such a situation is especially true in Alaskan waters where little work has been accomplished on the trophic relationships between various elements of food chains, and is certainly true in Prince William Sound where the only intensive studies available are those of the pink salmon (Helle *et al.*, 1964)[32]. The President's Panel on Oil Spills (1969)[33] states that "Effects of oil on birds, larger wildlife, and natural beauty are easy to observe, but effects on unobtrusive animals, microorganisms, and the net effects on the food chain and the ecological habitats of marine wildlife are poorly known". This is a statement that emphasizes the need for such studies in Alaska. The Panel also emphasizes the fact that most of our present knowledge of oil-spill damage is derived from observations on accidental oil spills and that we lack good data on organisms and their interrelationships before as well as after oil spills. It stated that, "A final assessment of the effects of oils and dispersants should be done in natural environments suited for comparative experiments. Monitoring of these experiments should be followed at least for one year to detect long-range effects".

Port Valdez is an area for which little biological baseline information was available at the time of its selection as a pipeline terminus. The need for knowledge of seasonal and long-term fluctuations as well as variations in species abundance for an area as necessary prerequisites for a biological baseline program has been stressed by Lewis (1970)[34]. It was with the latter need in mind that in 1972 an investigation of one component of the intertidal sediment ecosystem, the meiofauna (small organisms between 0.2 and 1.0 mm), of Port Valdez was initiated. The meiofauna is generally restricted to the upper few centimeters in fine sediments of the type found in Port Valdez (Barnett, 1968[35]; McIntyre, 1969[36]; also see Section IV), and should be vulnerable to oil layering on intertidal sediments following accidental spills as well as to the continuing presence of soluble fractions in the overlying sea water. Thus, basic information on the sediment meiofauna should be useful in the development of a monitoring program for Port Valdez.

No published work is available for Alaska concerning the small organisms (microflora, microfauna, meiofauna) that inhabit sediments. However, some assessment of the importance of these organisms in sediment systems can be extrapolated from work accomplished in other areas. The importance of bacteria as food for animals dwelling in sediments was emphasized by Zobell and Feltham (1938)[37] who calculated that in a cubic foot of mud there would be about a gram dry weight of bacteria with a production of at least 10 grams dry weight per day (also see Section IX for literature review). Green flagellates, diatoms and blue-green algae may also be abundant in and on estuarine muds and some diatoms and blue-green algae may form mats on the mud surface (Barnes, 1974)[18]. Bacteria and diatoms are eaten directly by many small members of the microfauna and meiofauna such as ciliate protozoans, turbellarian flatworms, nematodes, polychaetous annelids (young), ostracods and harpacticoid copepods (Barnes, 1974[18] for review; Boaden, 1962[38]; Fenchel, 1967[39]; McIntyre, 1969[36]; McIntyre and Murison, 1973[40]; Muus, 1967)[41], and are themselves consumed by other ciliates, flatworms, nematodes and halacarid mites. The microfauna and meiofauna are in turn fed upon by deposit feeding and predatory macrofauna such as various species of polychaete worms, crustacea, clams and small fishes (see Green, 1968[30] and Barnes, 1974[18] for review; Kaczynski *et al.*, 1973[42]; McIntyre and Murison, 1973[40]; Muus, 1967)[41]. Some of the latter organisms in many marine areas form part of the food for bottom fishes and wading birds (Barnes, 1974[18]; Green, 1968[30]; McIntyre and Murison, 1973)[40]. Damage to the meiofaunal components of the Port Valdez sediment system could seriously affect similar food-web interactions here at all trophic levels with possible alteration of species composition and abundance.

This section presents baseline data on meiofaunal as well as selected macrofaunal species on four beaches in Port Valdez and one beach in Galena Bay, Prince William Sound from July 1972 through July 1974. Aspects treated in this section include: general composition and density, vertical distribution, seasonal fluctuations, and reproductive biology of organisms on the above beaches.

METHODS

Three mid-tide sites (at 0.0 m), 4 m x 4 m, were selected for monthly sampling on beaches termed Dayville Flats, Island Flats (two sampling areas) and Mineral Creek Flats (see Section IV, Figure 1 for location of areas). Two additional beaches were sampled when time and logistics permitted, Galena Bay Flats (+ 0.8 m; adjacent to Millard Creek, Galena Bay) and Old Valdez (+ 0.9 m; adjacent to the site of Old Valdez). The latter site was available for one year only; the beach was markedly altered by activities associated with the razing of Old Valdez in the summer of 1973.

Core samples were taken monthly with a 3.5 cm internal diameter plastic core liner that sampled 10 cm^2 of sediment surface to a maximum depth of 8 cm. The core was held in a brass jacket with a threaded cap, and was split lengthwise to facilitate core removal. Five replicate cores were taken with the position of the first core selected randomly; the remaining cores were taken 35 cm apart in a line at right angles to the shore. In the field, five successive layers, each 1 cm thick, were sliced from four of the cores; three additional 1 cm layers were sliced from the fifth core. Each of the layers were placed in a separate jar and preserved in 10% neutral formalin with Rose Bengal (1 g/ℓ) added. Occasionally, living material was extracted by swirling fresh sediment with sea water, decanting the water through a 64 μ Nitex screen, and washing the organisms into a glass container for microscopic examination at the field station in Port Valdez.

Sediment, air, and water temperatures were taken routinely at each collection period and at other times whenever possible. Surface-water and sediment salinities were determined for most collection periods (see Section IV for data tables).

Preserved samples were elutriated and animals collected on 64 micron Nitex screening. Periodic microscopic examination for meiofaunal organisms in the residue after elutriation showed the procedure to be more than 95% efficient.

To facilitate counting, elutriated material from each core was divided into four subsamples with an aliquot sampler (R. T. Cooney, Inst. of Marine Science, University of Alaska, unpublished). Monthly counts of meiofauna and macrofauna from a single subsample were made. Periodically, a standard one-way analysis of variance was used on log transformed counts of the subsamples from a single core to demonstrate that the subsampling processes were unbiased for meiofauna; no significant differences between subsamples were typically detected (P = 0.05). Occasionally the subsampling method overestimated one species of copepod, the relatively large *Harpacticus uniremis* (see Section VII for detailed treatment of this species).

In February and June 1973 the Dayville sampling site (at 0.0 m) was divided into four quadrants, and twenty equally-spaced cores (four groups of five cores) were taken. Core counts of all nematodes and copepods were transformed to logarithmic values, and a One-Way Analysis of Variance used to test for significance. There was no significant difference between the population means for the four quadrants within the sampling site (P = 0.05).

Seasonal fluctuations are plotted as the mean number of animals counted per month in five cores.

RESULTS

Environment

Detailed environmental characteristics of the areas are included in Section IV.

Surficial sediment in the study areas vary somewhat, but, in general, can be described as a poorly sorted mud with a particle size range of 4 to 16 microns. The sediment texture is relatively uniform to 8 cm, the maximum depth sampled for meiofauna. The organic carbon content of the sediment is about 0.3%.

There are typically two low tides per day; lower tides occur during the day in spring and summer and at night in the winter. The study sites were exposed between 10 and 15 times per month.

Air temperatures in Port Valdez during the study period ranged from 17.5°C in August 1973 to -3.5°C in November 1973. Water temperatures during the period of investigation ranged from 15.6°C in June 1973 to 0.0°C in January 1974. Sediment temperatures roughly paralleled air temperatures at low tide and water temperatures at high tide; a minimum sediment surface temperature of -1.2°C was recorded at low tide in December 1972 (see Section IV, Tables 1, 2; Figures 4 and 5 this chapter).

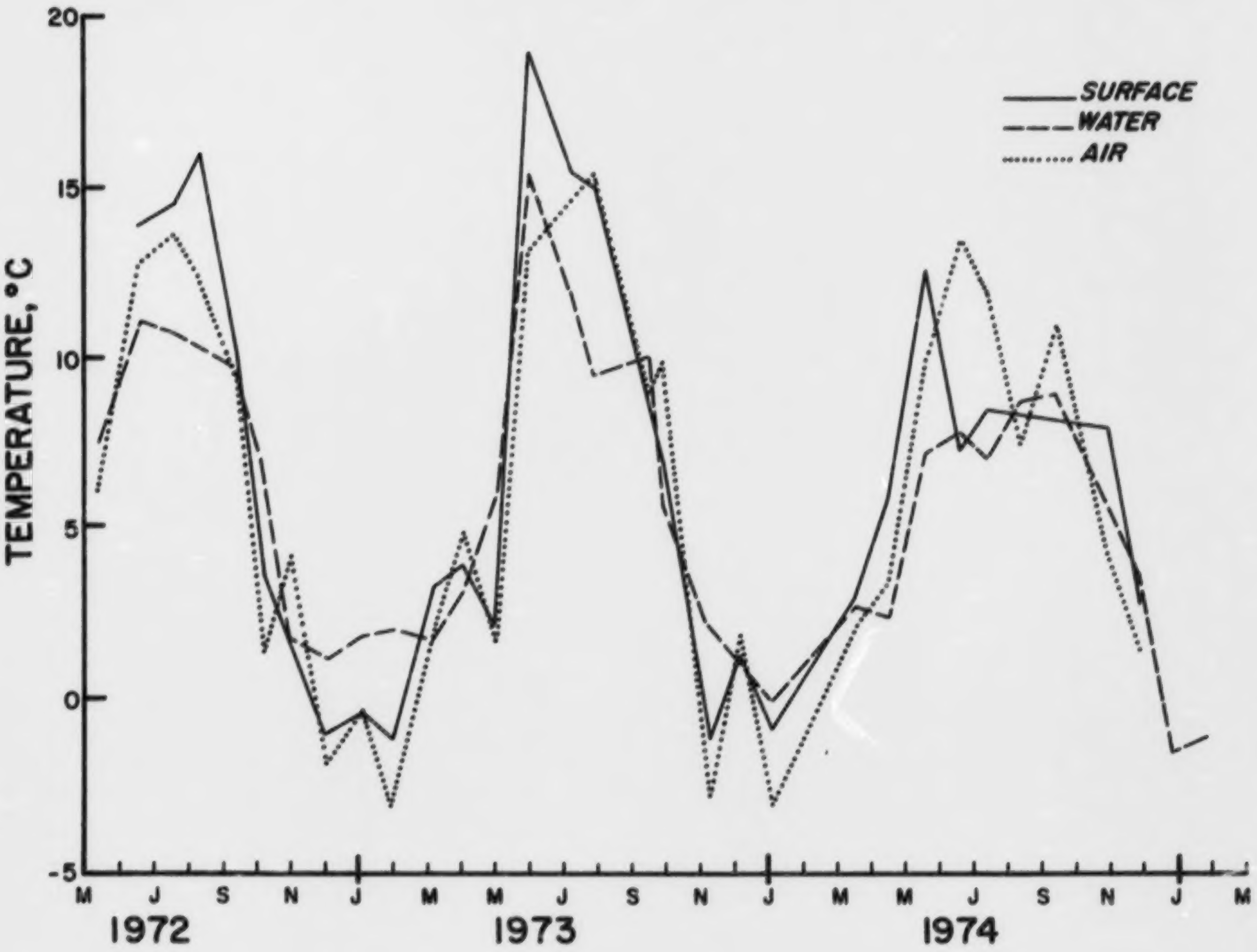

Figure 4. Sediment surface, water, and air temperatures in Port Valdez during the baseline study period.

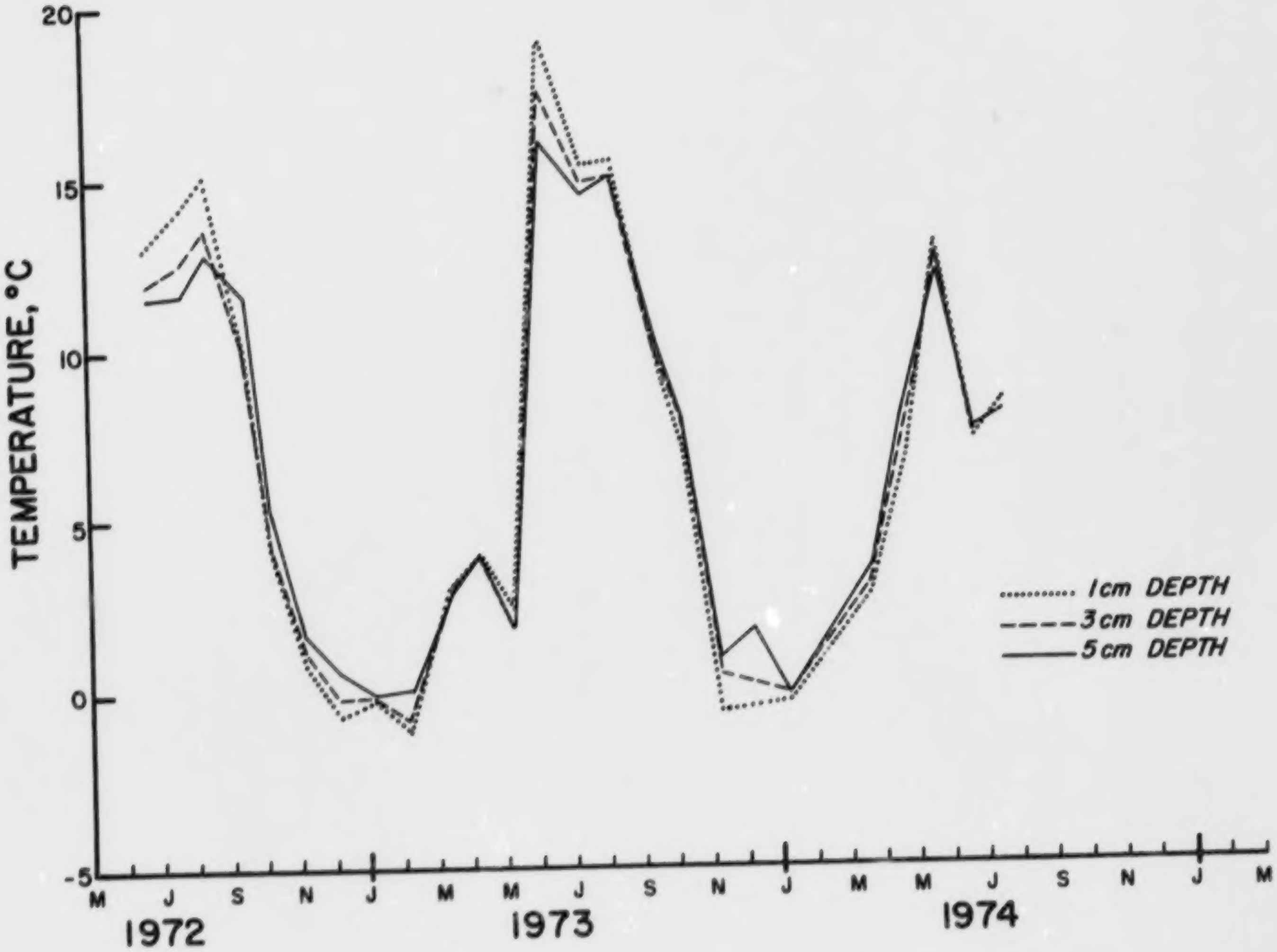

Figure 5. Sediment temperatures in Port Valdez during the baseline study period.

Winds are common at all seasons in Port Valdez, and contribute to low winter sediment temperatures at low tide as well as to the generation of small, high-frequency waves.

Surface ice occurs in winter and early spring, but thick sea ice rarely forms in Port Valdez. However, snow becomes saturated with water on the flats at low tide, freezes and forms sheets of ice varying in thickness from 1 cm to 1 m or more. This ice impinges upon and scours the tidal flats during slack water.

The salinity of surface water in Port Valdez varied from 0.3 °/₀₀ to 30.5 °/₀₀ for the period during which meiofaunal baseline collections were made. Interstitial salinities for the upper two centimeters of sediment ranged from 16.0 °/₀₀ in June 1974 to 36.2 in March 1974. Sediment salinities were consistently higher than that of the overlying sea water.

General Composition and Density of Organisms on all Study Beaches

The meiofauna consisted primarily of nematodes and harpacticoid copepods (Tables 18 through 22). Nematodes were not determined taxonomically. Eleven copepods were identified either to genus or species, or type but only eight species were sufficiently abundant to be followed quantitatively. Macrofaunal species were not systematically examined, and, with the exception of *Macoma balthica* (see Section XI) and some species of polychaetous annelids, are only listed as present in Port Valdez. All species collected are included in Table 23, the species examined quantitatively with time are included in Tables 24 through 43 and plotted in Figures 6 through 13.

A hydrozoan (*Protohydra* sp.), ostracods (two types), cumaceans (three types with the most common one *Cumella vulgaris*), and three types of unidentified mites occurred in smaller numbers on all beaches. At least five types of turbellarian flatworms and several species of nemerteans were observed alive in fresh sediment but none could be extracted quantitatively. Occasional foraminiferans, young amphipods, insect larvae, young clams (*Macoma balthica*) and young mussels (*Mytilus edulis*) occurred, but numbers of individuals were generally small. One species of meiofaunal polychaetous annelid, *Microphthalmus sczelkowii*, was observed on one occasion on Dayville Flats. One species*

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*Note: Continuation of text on page 109.

TABLE 18

DENSITIES OF TOTAL MEIOFAUNA, TOTAL NEMATODES AND TOTAL COPEPODS PER 10 CM^2 FROM AN INTERTIDAL SAMPLING STATION AT 0.0 M, DAYVILLE, PORT VALDEZ, ALASKA

Date of Sample	Total Meiofauna $\bar{X}$	Total Meiofauna SD	Total Nematodes $\bar{X}$	Total Nematodes SD	Total Copepods $\bar{X}$	Total Copepods SD
July 10, 1972	1636	135	1310	303	256	107
July 26, 1972	1927	1015	1586	927	309	82
Aug 9, 1972	2064	605	1703	569	351	132
Sept 8, 1972	2421	1441	2110	1169	307	274
Oct 7, 1972	1977	353	1703	343	255	52
Nov 11, 1972	1695	572	1413	474	252	116
Dec 6, 1972	2636	738	2306	620	293	160
Jan 2, 1973	3669	554	3426	621	216	85
Feb 4, 1973	2097	950	1896	777	132	102
Mar 7, 1973	2285	470	2226	482	46	16
Apr 4, 1973	2657	198	2050	256	135	41
May 5, 1973	1788	502	1548	436	126	56
June 4, 1973	1646	1323	1395	1119	242	204
July 1, 1973	2792	778	2521	736	206	67
July 30, 1973	3875	406	3496	436	284	72
Sept 13, 1973	3280	782	2940	751	252	98
Dec 7, 1973	1746	1031	1699	1005	26	22
Jan 7, 1974	802	454	762	437	26	22
Mar 25, 1974	2429	2324	2083	2179	251	156
Apr 24, 1974	1274	448	951	308	207	104
June 24, 1974	1752	510	1259	402	387	102
July 23, 1974	2050	493	1681	434	298	71

$\bar{X}$ = mean number of individuals from five cores.
SD = standard deviation.

TABLE 19

DENSITIES OF TOTAL MEIOFAUNA, TOTAL NEMATODES AND TOTAL COPEPODS PER 10 CM^2 FROM AN INTERTIDAL SAMPLING STATION AT 0.0 M, MINERAL CREEK, PORT VALDEZ, ALASKA

Date of Sample	Total Meiofauna		Total Nematodes		Total Copepods	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
July 13, 1972	656	135	307	102	230	42
July 28, 1972	839	253	429	153	286	81
Aug 9, 1972	909	964	704	783	151	135
Sept 7, 1972	2635	1071	1635	532	781	517
Oct 6, 1972	1360	563	965	294	292	163
Nov 4, 1972	1377	237	858	220	374	45
Dec 6, 1972	1625	367	1007	301	446	76
Feb 5, 1973	1208	362	802	171	285	180
Mar 20, 1973	954	353	750	348	140	23
Apr 5, 1973	1645	519	1362	316	185	191
May 3, 1973	2548	1010	1736	684	416	212
June 3, 1973	3862	1149	2849	852	718	294
July 14, 1973	2394	591	1561	46	554	171
Aug 1, 1973	4682	962	2753	581	1248	245
Sept 15, 1973	1518	834	1272	754	174	93
Nov 10, 1973	529	217	429	199	83	29
Dec 8, 1973	714	414	363	205	265	201
Jan 7, 1974	442	528	346	431	86	96
Mar 26, 1974	629	181	377	117	186	97
Apr 4, 1974	763	352	467	202	181	78
May 22, 1974[a]	1638	280	858	71	704	226
June 24, 1974	873	327	396	165	377	230
July 24, 1974	1483	260	997	189	415	122

$\bar{X}$ = mean number of individuals from five cores. SD = Standard Deviation

a = mean number of individuals from two cores.

TABLE 20

DENSITIES OF TOTAL MEIOFAUNA, TOTAL NEMATODES AND TOTAL COPEPODS PER 10 CM^2 FROM TWO INTERTIDAL SAMPLING STATIONS AT 0.0 M, BASELINE AND ALTERNATIVE STUDY BEACHES ON ISLAND FLATS, PORT VALDEZ, ALASKA

Date of Sample	Total Meiofauna $\bar{X}$	Total Meiofauna SD	Total Nematodes $\bar{X}$	Total Nematodes SD	Total Copepods $\bar{X}$	Total Copepods SD
a. Baseline Beach						
July 29, 1972	858	302	474	196	318	145
Nov 5, 1972	1997	278	1479	254	427	15
Apr 4, 1973	1674	483	917	294	289	43
May 4, 1973	1082	403	617	233	282	161
June 2, 1973	1870	548	888	289	922	358
June 29, 1973	1562	500	768	253	695	257
July 4, 1973[a]	4243	1862	2682	1167	1329	629
July 29, 1973	3357	1086	2202	1065	907	302
Sept 14, 1973	209	140	172	107	29	37
Nov 11, 1973	1220	304	765	387	364	121
Mar 25, 1974[b]	-	-	-	-	148	48
Apr 23, 1974[b]	-	-	-	-	97	36
b. Alternative Beach						
July 29, 1972	829	208	342	160	427	221
Nov 5, 1972	740	379	299	211	386	176

$\bar{X}$ = mean number of individuals from five cores.
SD = standard deviation.
a = mean number of individuals from five cores with counts made from the upper two centimeters of sediment only.
b = mean number of individuals from six unsplit cores with counts made from the upper first centimeter only. Only copepods counted.

TABLE 21

DENSITIES OF TOTAL MEIOFAUNA, TOTAL NEMATODES AND TOTAL COPEPODS PER 10 CM^2 FROM AN INTERTIDAL SAMPLING STATION AT 0.0 M, OLD VALDEZ, PORT VALDEZ, ALASKA

Date of Sample	Total Meiofauna		Total Nematodes		Total Copepods	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
July 26, 1972	1119	610	1034	567	48	28
Mar 10, 1973	2997	663	2749	638	104	66

$\bar{X}$ = mean number of individuals from five cores.
SD = standard deviation.

TABLE 22

DENSITIES OF TOTAL MEIOFAUNA, TOTAL NEMATODES AND TOTAL COPEPODS PER 10 CM^2 FROM AN INTERTIDAL SAMPLING STATION AT 0.0 M, GALENA BAY, PORT VALDEZ, ALASKA

Date of Sample	Total Meiofauna		Total Nematodes		Total Copepods	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
Nov 11, 1972	1078	313	993	298	16	13
Jan 21, 1973	494	182	478	176	10	7
Feb 22, 1973	322	99	179	27	56	19
Nov 9, 1973	252	104	97	45	75	35

$\bar{X}$ = mean number of individuals from five cores.
SD = standard deviation.

TABLE 23

LIST OF SPECIES COLLECTED ON ALL STUDY BEACHES IN PORT VALDEZ

Major Taxa	Species
PROTOZOA	Unidentified Foraminifera
CNIDARIA	*Protohydra* sp.
PLATYHELMINTHES	Approx. five unidentified species
NEMERTINEA	Unidentified species
NEMATHELMINTHES	Numerous unidentified species
ANNELIDA	
PHYLLODOCIDAE	*Eteone longa*
GONIADAE	*Glycinde picta*
SYLLIDAE	*Exogone lourei*
SYLLIDAE	*Microphthalmus sczelkowii*
SPIONIDAE	*Polydora quadrilobata*
CIRRATULIDAE	*Tharyx monilaris*
CAPITELLIDAE	*Capitella capitata*
GLYCERIDAE	*Glycera capitata*
SABELLIDAE	*Potamilla* sp.
ORBIINIDAE	*Haploscoloplos* sp.
MOLLUSCA	
PELECYPODA	*Macoma balthica*
PELECYPODA	*Mytilus edulis*
GASTROPODA	*Aglaja* sp.
TARDIGRADA	*Hypsibius appelloefi*
ARTHROPODA	
CRUSTACEA	
COPEPODA	*Harpacticus superflexus*[a]
COPEPODA	*Harpacticus uniremis* (Type 1)[b]
COPEPODA	*Nannopus palustris* (Type 2)
COPEPODA	*Rhizothrix* sp.[a]
COPEPODA	*Mesochra pygmaea?* (Type 3)
COPEPODA	*Halectinosoma gothiceps* (Type 4)
COPEPODA	*Halectinosoma finmarchicum* (Type 8)
COPEPODA	*Heterolaophonte* sp. (Type 10)
COPEPODA	*Paralaophonte perplexa*[a]
COPEPODA	*Microarthridion littorale* (Type 12)
COPEPODA	*Danielssenia typica*[a]
COPEPODA	Unidentified species
COPEPODA	*Stenhelia* sp.[a]
COPEPODA	*Paradactylopodia latipes*[a]
COPEPODA	*Tisbe inflata?* (Type 15)

TABLE 23 (Continued)

LIST OF SPECIES COLLECTED ON ALL STUDY BEACHES

Major Taxa	Species
OSTRACODA	Unidentified species
AMPHIPODA	Unidentified species
CUMACEA	Unidentified species; *Cumella vulgaris?*
ARACHNIDA	Unidentified species of mites
INSECTA	Unidentified species

[a] Species collected infrequently and in low numbers; not recorded in data tables by specific names.

[b] The number in parenthesis after taxonomic names are type numbers given during the study and prior to taxonomic determinations. These numbers occur in Tables 29 through 33.

TABLE 24

DENSITIES OF HARPACTICOID COPEPODS PER 10 CM^2 FROM AN INTERTIDAL SAMPLING STATION AT 0.0 M, DAYVILLE, PORT VALDEZ, ALASKA

Date of Sample	*Harpacticus uniremis*		*Halectinosoma gothiceps*		*Heterolaophonte* sp.		Unidentified Copepodites		Unidentified Nauplii		Other Copepods	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
July 10, 1972	98	27	121	88	20	13	-	-	-	-	15	9
July 26, 1972	143	50	110	35	47	7	-	-	-	-	9	8
Aug 9, 1972	203	112	94	54	8	7	-	-	-	-	47	11
Sept 8, 1972	94	112	98	110	11	8	-	-	-	-	105	39
Oct 7, 1972	18	13	95	60	80	81	-	-	5	9	61	48
Nov 11, 1972	7	8	134	57	3	7	-	-	6	5	106	36
Dec 6, 1972	18	10	37	36	0	0	17	23	2	2	236	105
Jan 2, 1973	32	24	31	26	0	0	2	4	10	17	151	54
Feb 4, 1973	5	4	8	9	0	0	-	-	58	120	119	42
Mar 7, 1973	0	0	3	4	0	0	2	2	10	23	41	18
Apr 4, 1973	6	2	10	5	0	0	26	17	424	194	119	32
May 5, 1973	31	14	17	11	0	0	60	73	6	7	79	25
June 4, 1973	46	45	45	55	12	26	-	-	-	-	138	45
July 1, 1973	51	15	24	23	2	2	-	-	-	-	128	40
July 30, 1973	39	27	28	22	54	73	-	-	10	6	165	86
Sept 13, 1973	42	13	19	16	48	96	8	11	-	-	143	66
Dec 7, 1973	4	3	11	11	2	4	2	2	-	-	9	4
Jan 7, 1974	2	2	7	7	0	0	1	2	-	-	16	6
Mar 25, 1974	84	78	60	35	7	8	33	49	-	-	101	35
Apr 24, 1974	77	51	78	42	9	5	8	9	-	-	44	13
June 24, 1974	73	68	195	32	25	10	21	28	1	2	94	26
July 23, 1974	40	11	147	43	13	7	-	-	1	2	98	26

$\bar{X}$ = mean number of individuals from five cores.
SD = standard deviation.

TABLE 25

DENSITIES OF HARPACTICOID COPEPODS PER 10 CM^2 FROM AN INTERTIDAL SAMPLING STATION AT 0.0 M, MINERAL CREEK, PORT VALDEZ, ALASKA

Date of Sample	*Harpacticus uniremis*		*Halectinosoma gothiceps*		*Heterolaophonte* sp.		Unidentified Copepodites		Unidentified Nauplii		Other Copepods	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
July 13, 1972	14	19	91	39	106	35	-	-	-	-	19	7
July 28, 1972	11	9	75	24	133	38	-	-	-	-	66	34
Aug 9, 1972	12	8	54	45	10	5	-	-	-	-	76	35
Sept 7, 1972	74	40	458	391	121	81	-	-	42	90	124	32
Oct 6, 1972	9	11	103	51	100	81	-	-	7	9	78	23
Nov 4, 1972	1	1	193	28	0	0	-	-	15	24	180	34
Dec 6, 1972	106	63	171	15	0	0	11	17	4	7	167	42
Feb 5, 1973	2	2	125	115	0	0	10	11	21	22	158	44
Mar 20, 1973	3	3	78	30	0	0	4	3	-	-	59	20
Apr 5, 1973	8	7	102	63	1	1	4	22	2	2	74	46
May 3, 1973	86	41	166	89	0	0	108	83	8	11	163	36
June 3, 1973	26	18	527	257	61	59	-	-	-	-	105	19
July 14, 1973	15	8	416	127	88	41	-	-	-	-	34	9
Aug 1, 1973	12	5	927	192	162	32	-	-	3	4	148	29
Sept 15, 1973	4	5	119	83	20	11	-	-	4	8	31	9
Nov 10, 1973	1	1	48	21	10	2	2	2	-	-	25	6
Dec 8, 1973	0	0	158	122	81	80	8	11	-	-	27	6
Jan 7, 1974	2	2	22	23	7	12	2	4	-	-	55	22
Mar 26, 1974	3	5	115	78	15	14	1	3	-	-	54	13
Apr 4, 1974	21	15	93	59	26	17	38	27	-	-	40	7
May 22, 1974[a]	60	11	400	136	150	37	14	20	-	-	94	19
June 24, 1974	13	15	273	150	63	113	-	-	-	-	27	8
July 24, 1074	6	4	333	101	41	20	-	-	-	-	35	10

$\bar{X}$ = mean number of individuals from five cores.
SD = standard deviation.
a = mean numbers from two cores.

TABLE 26

DENSITIES OF HARPACTICOID COPEPODS PER 10 CM^2 FROM TWO INTERTIDAL SAMPLING STATIONS AT 0.0 M, BASELINE AND ALTERNATIVE STUDY BEACHES ON ISLAND FLATS, PORT VALDEZ, ALASKA

Date of Sample	*Harpacticus uniremis*		*Halectinosoma gothiceps*		*Heterolaophonte* sp.		Unidentified Copepodites		Unidentified Nauplii		Other Copepods	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
a. Baseline Beach												
July 29, 1972	107	74	93	65	0	0	-	-	-	-	119	77
Nov 5, 1972	10	8	182	107	0	0	1	2	6	14	234	66
Apr 4, 1973	0	0	134	34	0	0	15	13	423	269	155	28
May 4, 1073	52	42	94	59	2	4	113	76	55	33	134	45
June 2, 1973	217	155	362	138	48	53	5	11	6	9	297	44
June 29, 1973	41	16	345	209	138	36	7	11	6	12	173	27
July 4, 1973[a]	106	67	690	295	263	128	6	13	7	7	270	46
July 29, 1973	44	33	469	222	142	66	31	33	25	29	254	53
Sept 14, 1973	0	0	18	21	5	8	-	-	-	-	6	6
Nov 11, 1973	1	2	216	67	28	19	14	5	2	4	119	22
Mar 25, 1974[b]	2	2	105	32	13	10	unknown		-	-	28	10
Apr 23, 1974[b]	17	5	45	22	25	8	unknown		-	-	11	4
b. Alternative Beach												
July 29, 1972	45	34	155	69	0	0	-	-	2	4	228	37
Nov 5, 1972	3	5	153	90	0	0	-	-	5	7	229	63

$\bar{X}$ = mean number of individuals from five cores.
SD = standard deviation.
a = mean numbers from five cores with counts taken from the upper two centimeters of sediment only.
b = mean numbers from six unsplit cores with counts taken from the upper first centimeter of sediment only. Only copepods counted.

TABLE 27

DENSITIES OF HARPACTICOID COPEPODS PER 10 CM^2 FROM AN INTERTIDAL SAMPLING STATION AT 0.0 M, OLD VALDEZ, PORT VALDEZ, ALASKA

Date of Sample	*Harpacticus uniremis*		*Halectinosoma gothiceps*		*Heterolaophonte* sp.		Unidentified Copepodites		Unidentified Nauplii		Other Copepods	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
July 26, 1972	8	17	8	7	0	0	-	-	-	-	30	22
Mar 10, 1973	10	12	42	34	0	0	-	-	-	-	53	28

$\bar{X}$ = mean number of individuals from five cores.
SD = standard deviation.

TABLE 28

DENSITIES OF HARPACTICOID COPEPODS PER 10 CM^2 FROM AN INTERTIDAL SAMPLING STATION AT 0.0 M, GALENA BAY, PORT VALDEZ, ALASKA

Date of Sample	*Harpacticus uniremis*		*Halectinosoma gothiceps*		*Heterolaophonte* sp.		Unidentified Copepodites		Unidentified Nauplii		Other Copepods	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
Nov 11, 1972	4	2	1	2	0	0	-	-	-	-	12	13
Jan 2, 1973	0	0	1	2	0	0	1	2	-	-	9	7
Feb 22, 1973	7	8	38	17	0	0	2	5	1	2	12	5
Nov 9, 1973	9	10	21	21	2	3	-	-	-	-	41	16

$\bar{X}$ = mean number of individuals from five cores.
SD = standard deviation.

TABLE 29

DENSITIES OF "OTHER COPEPODS"[a] PER 10 CM^2 FROM AN INTERTIDAL SAMPLING STATION AT 0.0 M, DAYVILLE, PORT VALDEZ, ALASKA

Date of Sample	Other Copepods[a]		Type 2		Type 3		Type 8		Type 9		Type 11		Type 12		Type 13		Type 15	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
July 10, 1972	15	9	7	13	6	4	2	3	-	-	-	-	-	-	-	-	-	-
July 26, 1972	9	8	-	-	9	8	-	-	-	-	-	-	-	-	-	-	-	-
Aug 9, 1972	47	11	2	4	11	6	8	8	3	7	10	17	13	19	-	-	-	-
Sept 8, 1972	105	39	3	3	2	4	22	31	-	-	-	-	78	39	-	-	-	-
Oct 7, 1972	61	48	-	-	-	-	2	4	-	-	-	-	59	54	-	-	-	-
Nov 11, 1972	106	36	69	49	2	3	-	-	-	-	24	15	11	8	-	-	-	-
Dec 6, 1972	236	105	193	135	1	2	-	-	-	-	17	27	25	50	-	-	-	-
Jan 2, 1973	151	54	105	62	20	42	-	-	-	-	2	4	24	19	-	-	-	-
Feb 4, 1973	119	42	8	17	4	5	68	55	-	-	1	2	38	52	-	-	-	-
Mar 4, 1973	41	18	7	12	-	-	5	3	-	-	-	-	29	23	-	-	-	-
Apr 4, 1973	119	32	13	7	6	4	49	27	-	-	-	-	51	44	-	-	-	-
May 5, 1973	79	25	9	4	2	3	13	16	-	-	-	-	55	21	-	-	-	-
June 4, 1973	138	45	14	14	10	17	9	9	-	-	-	-	105	123	-	-	-	-
July 1, 1973	128	40	-	-	3	4	11	5	-	-	-	-	114	41	-	-	-	-
July 30, 1973	165	86	-	-	-	-	8	10	-	-	-	-	157	60	-	-	-	-
Sept 13, 1973	143	66	2	2	2	4	5	5	-	-	-	-	134	118	-	-	-	-
Dec 7, 1973	9	4	3	7	2	4	2	4	-	-	-	-	2	2	-	-	-	-
Jan 7, 1974	16	6	2	2	2	4	2	4	-	-	1	2	9	11	-	-	-	-
Mar 25, 1974	101	35	-	-	13	12	78	38	-	-	-	-	10	10	-	-	2	3
Apr 24, 1974	44	13	1	2	15	19	22	11	-	-	-	-	6	5	-	-	-	-
June 24, 1974	94	26	-	-	18	17	10	6	-	-	-	-	66	17	-	-	-	-
July 22, 1974	98	26	2	4	23	14	12	10	-	-	-	-	61	18	-	-	-	-

$\bar{X}$ = mean number of individuals from five cores. SD = standard deviation.

a = Other identified copepods include: Type 2 *Nannopus palustris*, Type 3 *Mesochra pygmaea?*, Type 8 *Halectinosoma finmarchicum*, Type 12 *Microarthridion littorale*, and Type 15 *Tisbe inflata?*

TABLE 30

DENSITIES OF "OTHER COPEPODS"[a] PER 10 CM^2 FROM AN INTERTIDAL SAMPLING STATION AT 0.0 M, MINERAL CREEK, PORT VALDEZ, ALASKA

Date of Sample	Other Copepods		Type 2		Type 3		Type 8		Type 9		Type 11		Type 12		Type 13		Type 15	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
July 13, 1972	19	7	3	4	3	1	13	7	-	-	-	-	-	-	-	-	-	-
July 28, 1972	66	34	-	-	17	14	2	2	-	-	49	47	-	-	-	-	-	-
Aug 9, 1972	76	35	58	67	9	8	1	2	-	-	3	7	5	8	-	-	-	-
Sept 7, 1972	127	32	61	46	28	35	6	6	-	-	10	10	23	9	-	-	-	-
Oct 6, 1972	78	23	19	9	8	9	1	2	-	-	11	16	39	40	-	-	-	-
Nov 4, 1972	180	34	72	14	14	11	-	-	-	-	25	23	69	30	-	-	-	-
Dec 6, 1972	167	42	105	28	15	12	-	-	-	-	32	19	15	14	-	-	-	-
Feb 5, 1973	158	44	28	34	16	15	64	53	-	-	2	3	43	31	5	4	-	-
Mar 20, 1973	59	20	24	36	6	8	14	9	-	-	-	-	15	12	-	-	-	-
Apr 5, 1973	74	46	4	8	7	9	21	11	-	-	-	-	42	15	-	-	-	-
May 3, 1973	163	36	23	35	40	23	34	40	-	-	-	-	65	40	1	2	-	-
June 3, 1973	105	19	9	5	20	13	28	16	-	-	2	3	45	28	-	-	-	-
July 14, 1973	34	9	4	5	2	2	-	-	-	-	15	12	13	11	-	-	-	-
Aug 1, 1973	48	29	7	6	41	39	5	10	-	-	24	21	71	31	-	-	-	-
Sept 15, 1973	31	9	2	4	6	6	2	2	-	-	-	-	21	14	-	-	-	-
Nov 10, 1973	25	6	-	-	11	12	2	2	-	-	3	3	9	2	-	-	-	-
Dec 8, 1973	27	6	3	5	6	7	3	4	-	-	6	6	9	11	-	-	-	-
Jan 7, 1974	55	22	1	2	-	-	23	37	-	-	5	8	26	28	-	-	-	-
Mar 26, 1974	54	13	1	3	11	11	19	22	-	-	13	16	3	5	-	-	7	14
Apr 4, 1974	40	7	1	2	8	7	11	5	-	-	6	6	3	4	-	-	11	11
May 22, 1974[b]	94	19	10	8	44	6	18	14	-	-	20	28	2	3	-	-	-	-
June 24, 1974	27	8	3	3	7	3	1	2	-	-	11	17	5	8	-	-	-	-
July 24, 1974	35	10	5	5	9	12	2	3	-	-	1	2	18	12	-	-	-	-

$\bar{X}$ = mean number of individuals from five cores. SD = standard deviation.

a = Other identified copepods include: Type 2 *Nannopus palustris*, Type 3 *Mesochra pygmaea?*, Type 8 *Halectinosoma finmarchicum*, Type 12 *Microarthridion littorale*, and Type 15 *Tisbe inflata?*

b = mean number of individuals from two cores.

TABLE 31

DENSITIES OF "OTHER COPEPODS"[a] PER 10 CM^2 FROM TWO INTERTIDAL SAMPLING STATIONS AT 0.0 M, BASELINE AND ALTERNATIVE STUDY BEACHES ON ISLAND FLATS, PORT VALDEZ, ALASKA

Date of Sample	Other Copepods		Type 2		Type 3		Type 8		Type 9		Type 11		Type 12		Type 13		Type 15	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
a. Baseline Beach																		
July 29, 1972	119	77	78	30	2	2	-	-	-	-	1	1	38	19	-	-	-	-
Nov 5, 1972	234	66	78	32	93	123	6	14	-	-	2	2	55	39	-	-	-	-
Apr 4, 1973	155	28	24	14	35	28	71	30	-	-	-	-	25	9	-	-	-	-
May 4, 1973	134	45	27	30	15	23	7	10	-	-	-	-	85	59	-	-	-	-
June 2, 1973	297	44	46	15	83	47	32	47	-	-	2	4	134	42	-	-	-	-
June 29, 1973	173	27	33	20	12	12	18	9	-	-	8	9	102	20	-	-	-	-
July 4, 1973[b]	270	46	38	22	101	67	33	54	-	-	11	14	87	50	-	-	-	-
July 29, 1973	254	53	69	34	21	14	3	3	-	-	15	11	146	65	-	-	-	-
Sept 14, 1973	6	6	5	8	-	-	-	-	-	-	-	-	1	2	-	-	-	-
Nov 11, 1973	119	22	11	9	32	16	8	7	-	-	7	7	61	26	-	-	-	-
Mar 25, 1974[c]	28	10	6	3	5	3	3	4	-	-	-	-	14	21	-	-	-	-
Apr 23, 1974[c]	11	4	1	2	1	1	3	4	-	-	-	-	6	6	-	-	-	-
b. Alternative Beach																		
July 29, 1972	228	37	65	46	107	145	-	-	-	-	34	15	22	11	-	-	-	-
Nov 5, 1972	229	63	50	20	23	21	-	-	-	-	138	81	1	2	17	38	-	-

$\bar{X}$ = mean number of individuals from five cores. SD = standard deviation.

a = Other identified copepods include: Type 2 *Nannopus palustris*, Type 3 *Mesochra pygmaea?*, Type 8 *Halectinosoma finmarchicum*, Type 12 *Microarthridion littorale*, and Type 15 *Tisbe inflata?*

b = mean number of individuals from five cores with counts made from the upper 2 centimeters of sediment only.

c = mean number of individuals from six unsplit cores with counts made from the upper first centimeter of sediment only. Only copepods counted.

TABLE 32

DENSITIES OF "OTHER COPEPODS"[a] PER 10 CM^2 FROM AN INTERTIDAL SAMPLING STATION AT 0.0 M, OLD VALDEZ, PORT VALDEZ, ALASKA

Date of Sample	Other Copepods		Type 2		Type 3		Type 8		Type 9		Type 11		Type 12		Type 13		Type 15	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
July 26, 1972	31	22	20	20	-	-	-	-	-	-	10	15	-	-	-	-	-	-
Mar 10, 1973	53	28	30	27	-	-	-	-	-	-	-	-	23	31	-	-	-	-

$\bar{X}$ = mean number of individuals from five cores.
SD = standard deviation.
a = Other identified copepods include: Type 2 *Nannopus palustris*, Type 3 *Mesochra pygmaea?*, Type 8 *Halectinosoma finmarchicum*, Type 12 *Microarthridion littorale*, and Type 15 *Tisbe inflata?*

TABLE 33

DENSITIES OF "OTHER COPEPODS" PER 10 CM^2 FROM AN INTERTIDAL SAMPLING STATION AT 0.0 M, GALENA BAY, PORT VALDEZ, ALASKA

Date of Sample	Other Copepods		Type 2		Type 3		Type 8		Type 9		Type 11		Type 12		Type 13		Type 15	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
Nov 11, 1972	12	13	12	13	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Jan 21, 1973	9	7	8	8	-	-	1	2	-	-	-	-	-	-	-	-	-	-
Feb 22, 1973	12	5	9	3	2	4	1	2	-	-	-	-	-	-	-	-	-	-
Nov 9, 1973	41	16	32	11	2	5	-	-	-	-	1	2	-	-	-	-	6	13

$\bar{X}$ = mean number of individuals from five cores.
SD = standard deviation.
a = Other identified copepods include: Type 2 *Nannopus palustris*, Type 3 *Mesochra pygmaea?*, Type 8 *Halectinosoma finmarchicum*, Type 12 *Microarthridion littorale*, and Type 15 *Tisbe inflata?*

TABLE 34

DENSITIES OF OTHER MEIOFAUNA PER 10 CM^2 FROM AN INTERTIDAL SAMPLING STATION AT 0.0 M, DAYVILLE, PORT VALDEZ, ALASKA

Date of Sample	Foraminifera		Protohydra		Ostracods Type 1		Ostracods Type 2		Cumaceans Type 1		Cumaceans Type 2		Cumaceans Type 3		Amphipods		Mites Type 1		Mites Type 2		Mites Type 4	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
July 10, 1972	-	-	1	2	-	-	-	-	1	2	-	-	63	83	1	2	1	2	2	3	-	-
July 26, 1972	-	-	-	-	-	-	-	-	1	2	-	-	26	18	-	-	-	-	4	6	-	-
Aug 9, 1972	-	-	2	2	-	-	-	-	-	-	-	-	-	-	3	4	-	-	5	3	-	-
Sept 8, 1972	-	-	-	-	-	-	-	-	-	-	-	-	3	5	-	-	-	-	2	2	-	-
Oct 7, 1972	-	-	3	3	1	2	-	-	-	-	-	-	6	4	-	-	1	2	3	7	-	-
Nov 11, 1972	-	-	7	5	1	2	4	4	-	-	-	-	10	10	-	-	2	4	2	2	-	-
Dec 6, 1972	-	-	5	9	2	2	5	6	-	-	-	-	-	-	1	2	-	-	6	2	-	-
Jan 21, 1973	-	-	3	7	-	-	-	-	2	5	-	-	2	4	1	2	-	-	6	8	-	-
Feb 4, 1973	-	-	2	2	-	-	1	2	-	-	2	2	-	-	-	-	-	-	3	3	-	-
Mar 7, 1973	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	4	-	-	-	-
Apr 4, 1973	6	4	3	4	1	2	1	2	-	-	5	2	-	-	-	-	-	-	4	6	2	2
May 5, 1973	-	-	2	4	-	-	-	-	-	-	-	-	1	2	1	2	-	-	2	5	38[b]	71[b]
June 4, 1973	-	-	3	3	1[a]	2	-	-	-	-	-	-	-	-	-	-	-	-	59	-	-	-
July 1, 1973	-	-	14	8	-	-	-	-	-	-	3	4	31	22	-	-	1	2	12	3	4	7
July 30, 1973	-	-	15	12	1	2	6	5	-	-	-	-	30	22	1	2	2	4	28	8	-	-
Sept 13, 1973	-	-	32	19	2	2	5	5	-	-	-	-	26	11	-	-	-	-	14	18	-	-
Dec 7, 1973	-	-	10	11	-	-	-	-	-	-	-	-	1	2	-	-	-	-	7	7	-	-
Jan 7, 1974	1	2	2	4	-	-	1	2	-	-	6	6	2	2	-	-	-	-	2	2	-	-
Mar 25, 1974	-	-	42	26	-	-	3	4	-	-	1	2	1	2	-	-	-	-	16	15	-	-
Apr 24, 1974	-	-	70	63	1	2	2	4	3	5	3	3	-	-	-	-	-	-	28	7	-	-
June 24, 1974	-	-	3	4	11	9	7	6	-	-	-	-	37[a]	15	1	2	-	-	23	11	-	-
July 24, 1974	-	-	11	3	7	5	4	4	-	-	-	-	27[a]	7	-	-	-	-	21	5	-	-

$\bar{X}$ = mean number of individuals from five cores.
a = species type unknown
b = species Type 6

SD = standard deviation

TABLE 35

DENSITIES OF OTHER MEIOFAUNA PER 10 CM^2 FROM AN INTERTIDAL SAMPLING STATION AT 0.0 M, MINERAL CREEK, PORT VALDEZ, ALASKA

Date of Sample	Foraminifera		Protohydra		Ostracods				Cumaceans						Amphipods		Mites					
					Type 1		Type 2		Type 1		Type 2		Type 3				Type 1		Type 2		Type 4	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
July 13, 1972	50	68	12	8	7	5	5	3	–	–	–	–	28	17	–	–	3	7	13	14	–	–
July 28, 1972	38	40	8	2	18	7	12	4	–	–	–	–	34	24	2	3	2	4	10	7	–	–
Aug 9, 1972	5	4	2	4	5	8	9	10	–	–	1	2	28	23	–	–	–	–	2	5	–	–
Sept 7, 1972	66	35	12	9	10	17	5	5	9	12	–	–	50	29	–	–	19^c	23	6	8	1	2
Oct 6, 1972	14	13	13	13	15	16	5	3	–	–	8	13	26	24	–	–	–	–	15	15	–	–
Nov 4, 1972	37	22	14	9	23	7	10	2	–	–	–	–	38	22	–	–	–	–	7	6	2	3
Dec 6, 1972	17	18	21	21	4	2	27	19	–	–	1	2	6	4	–	–	1	2	80	40	–	–
Feb 5, 1973	16	13	2	2	18	8	9	5	–	–	3	5	1	2	3	1	2	3	36	21	–	–
Mar 20, 1973	20	17	–	–	9	9	3	7	–	–	–	–	5	5	–	–	14	20	10	12	–	–
Apr 5, 1973	11	7	2	2	5	5	2	7	–	–	–	–	–	–	–	–	1	2	51	42	–	–
May 3, 1973	161	101	3	3	5	4	6	8	8	9	6	8	1	2	–	–	–	–	90	58	–	–
June 3, 1973	171	56	1	2	16	11	7	7	2	4	–	–	2	4	8	11	–	–	88	44	–	–
July 14, 1973	150	96	6	7	6	7	21	10	–	–	10	10	23	18	–	–	–	–	64	52	–	–
Aug 1, 1973	390	122	27	19	22	13	17	8	–	–	7	11	24	20	–	–	–	–	190	75	–	–
Sept 15, 1973	24	14	2	3	10	7	8	8	–	–	–	–	2	4	–	–	1	3	20	7	–	–
Nov 10, 1973	–	–	2	4	2	3	2	3	–	–	–	–	–	–	–	–	–	–	8^b	7	–	–
Dec 8, 1973	5	7	7	6	2	4	3	3	–	–	–	–	2	2	–	–	–	–	59	58	–	–
Jan 7, 1974	–	–	–	–	2	3	2	3	–	–	–	–	–	–	–	–	–	–	3	4	–	–
Mar 26, 1974	33	41	2	3	6	4	2	3	–	–	–	–	1	2	–	–	1^d	2	20	21	–	–
Apr 4, 1974	32	39	–	–	9	11	4	5	–	–	–	–	2	2	–	–	–	–	32	22	–	–
May 22, 1974[a]	–	–	–	–	2	3	6	8	–	–	–	–	4	0	2	3	2^d	3	46	14	–	–
June 24, 1974	59	22	8	9	5	5	–	–	–	–	–	–	14	10	2	2	–	–	12	17	–	–
July 24, 1974	–	–	11	9	11	5	7	6	–	–	–	–	12^b	6	–	–	–	–	30	16	–	–

$\bar{X}$ = mean number of individuals from five cores.
SD = standard deviation
a = mean number of individuals from two cores.

b = species type unknown
c = species type 3
d = species type Isopod

TABLE 36

DENSITIES OF OTHER MEIOFAUNA PER 10 CM^2 FROM TWO INTERTIDAL SAMPLING STATIONS AT 0.0 M, BASELINE AND ALTERNATIVE STUDY BEACHES ON ISLAND FLATS, PORT VALDEZ, ALASKA

Date of Sample	Foraminifera		Protohydra		Ostracods				Cumaceans						Amphipods		Mites				Tardigrades	
					Type 1		Type 2		Type 1		Type 2		Type 3				Type 2		Type 4			
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
a. Baseline Beach																						
July 29, 1972	-	-	42	25	1	2	6	5	-	-	2	2	7	5	-	-	8	9	-	-	-	-
Nov 5, 1972	-	-	11	9	18	12	12	10	-	-	-	-	7	7	-	-	29	4	1	2	-	-
Apr 4, 1973	2	2	4	5	3	5	4	5	2	3	-	-	3	5	-	-	11	7	-	-	1	2
May 4, 1973	-	-	1	2	3	4	5	7	-	-	-	-	-	-	-	-	6	6	-	-	-	-
June 2, 1973	6	10	3	5	6	4	13	14	-	-	2	5	-	-	1	2	17	18	-	-	1	2
June 29, 1973	9	10	6	7	17	15	17	15	-	-	-	-	5	5	-	-	29	14	-	-	2	5
July 4, 1973[a]	30	24	2	4	55	26	49	39	-	-	2	4	14	12	-	-	67	36	-	-	1	2
July 29, 1973	7	5	8	5	34	27	37	28	-	-	2	2	36	30	-	-	67	20	-	-	1	2
Sept 14, 1973	-	-	2	5	1	2	-	-	-	-	-	-	-	-	-	-	3	4	-	-	-	-
Nov 11, 1973	8	6	6	10	27	20	10	15	-	-	-	-	1[b]	2	-	-	23	15	1	2	-	-
b. Alternative Beach																						
July 29, 1972	2	4	9	7	5	5	7	4	2	2	-	-	22	12	-	-	11	10	-	-	-	-
Nov 5, 1972	18	14	5	5	5	4	5	5	-	-	-	-	6	5	-	-	10	5	-	-	-	-

$\bar{X}$ = mean number of individuals from five cores.
SD = standard deviation
a = mean number of individuals from five cores with counts made from the upper two centimeters of sediment only.
b = species type unknown.

TABLE 37

DENSITIES OF OTHER MEIOFAUNA PER 10 CM^2 FROM AN INTERTIDAL SAMPLING STATION AT 0.0 M, OLD VALDEZ, ALASKA

Date of Sample	Foraminifera		Protohydra		Ostracods				Cumaceans						Mites						Tardigrades	
					Type 1		Type 2		Type 1		Type 2		Type 3		Type 1		Type 2		Type 4			
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
July 26, 1972	-	-	9	13	1	2	2	3	-	-	-	-	-	-	1	2	4	7	2	3	16	8
Mar 10, 1973	-	-	-	-	31	13	-	-	-	-	-	-	-	-	6	7	4	4	-	-	102	77

$\bar{X}$ = mean number of individuals from five cores.
SD = standard deviation.

TABLE 38

DENSITIES OF OTHER MEIOFAUNA PER 10 CM^2 FROM AN INTERTIDAL SAMPLING STATION AT 0.0 M, GALENA BAY, PORT VALDEZ, ALASKA

Date of Sample	Foraminifera		Protohydra		Ostracods				Cumaceans						Mites						Tardigrades	
					Type 1		Type 2		Type 1		Type 2		Type 3		Type 1		Type 2		Type 4			
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
Nov 11, 1972	-	-	-	-	12	8	47	45	-	-	-	-	1^a	2	1	2	-	-	-	-	7	5
Jan 21, 1973	2	4	-	-	-	-	-	-	-	-	-	-	-	-	2	4	2	4	-	-	1	2
Feb 22, 1973	6	8	5	7	23	37	1	2	-	-	49	25	-	-	-	-	-	-	-	-	1	2
Nov 9, 1973	-	-	-	-	7	9	-	-	14^a	18	8	10	31	29	-	-	-	-	-	-	19	27

$\bar{X}$ = mean number of individuals from five cores.
SD = standard deviation.
a = species type unknown.

TABLE 39

MEAN DENSITIES OF OTHER FAUNA PER 10 CM^2 FROM AN INTERTIDAL SAMPLING STATION AT 0.0 M, DAYVILLE, PORT VALDEZ, ALASKA

Date of Sample	Flat-worms	*Macoma balthica*	Other Larvae	Unknowns	*Exogone*	Polychaetes *Polydora*	*Capitella*	*Tharyx*	Others	Frags.	Total
July 10, 1972	6	1	-	10	8	6	-	-	-	-	24
July 26, 1972	-	6	-	33	19	1	-	-	-	-	53
Aug 9, 1972	2	1	-	52	-	-	-	-	-	-	52
Sept 8, 1972	-	-	6 Collembola	28	-	-	-	-	-	-	28
Oct 7, 1972	-	-	1 Collembola	4	2	-	-	-	1 *Glycinde*	-	7
Nov 11, 1972	-	-	-	11	-	-	-	-	-	-	11
Dec 6, 1972	-	-	-	15	-	-	-	-	-	-	15
Jan 2, 1973	-	16	5 insect larvae 2 mussels 3 Collembola	10	3	-	-	-	-	1	13
Feb 4, 1973	2	-	1 unid. larva	-	4	2	-	-	-	6	6
Mar 7, 1973	2	-	-	2	1	1	-	-	-	1	4
Apr 4, 1973	2	7	-	10	1	-	-	-	1 *Eteone*	3	12
May 5, 1973	-	-	-	2	2	-	-	-	1 *Eteone* 1 *Glycinde*	-	6
June 4, 1973	1	1	1 insect larva 1 mussel	1	17	2	-	1	2 *Eteone* 2 *Glycinde*	-	25
July 1, 1973	16	many young	1 insect larva 1 mussel	-	20	-	-	-	-	1	20
July 30, 1973	3	513 young	8 insect larva 3 mussels	4	11	-	-	-	1 *Glycinde*	9	16
Sept 13, 1973	1	24	9 insect larva 33 mussels	2	29	-	1	2	1 *Eteone* 1 *Potamella*	1	36
Dec 7, 1973	-	5	2 larvae 2 mussels	9	-	-	-	-	-	-	9
Jan 7, 1974	-	2	3 larvae 2 mussels	-	4	-	-	-	-	2	4

TABLE 39 (Continued)

MEAN DENSITIES OF OTHER FAUNA PER 10 CM^2 FROM AN INTERTIDAL SAMPLING STATION AT DAYVILLE

					Polychaetes						
Date of Sample	Flat-worms	*Macoma balthica*	Other Larvae	Unknowns	*Exogone*	*Polydora*	*Capitella*	*Tharyx*	Others	Frags.	Total
Mar 25, 1974	-	11	1 insect larva	-	11	-	-	3	1 *Haploscoloplos* 5 *Potamella*	-	20
Apr 24, 1974	-	2	1 larvae 2 mussels	-	1	1	-	1	6 *Potamella*	-	9
June 24, 1974	-	-	1 Collembola	-	NONE RECORDED						
July 23, 1974	-	-	-	-	NONE RECORDED						

TABLE 40

MEAN DENSITIES OF OTHER FAUNA PER 10 CM^2 FROM AN INTERTIDAL SAMPLING STATION AT 0.0 M, MINERAL CREEK, PORT VALDEZ, ALASKA

Date of Sample	Flat-worms	*Macoma balthica*	Other Larvae	Unknowns	Polychaetes *Exogone*	 *Polydora*	 *Capitella*	 *Tharyx*	 Others	Frags.	Total
July 13, 1972	5	-	-	38	-	6	-	-	-	-	44
July 28, 1972	2	-	-	17	6	31	-	-	-	2	54
Aug 9, 1972	1	2	-	25	-	-	-	-	-	-	25
Sept 7, 1972	-	-	-	11	-	2	-	-	-	-	13
Oct 6, 1972	1	-	-	12	-	-	-	-	-	-	12
Nov 4, 1972	-	2	-	9	3	-	-	-	2 *Glycinde*	-	14
Dec 6, 1972	-	-	-	37	-	-	-	-	-	-	37
Feb 5, 1973	14	1	6 insect larva 5 Collembola	20	3	14	-	-	7 *Eteone* 1 *Glycinde*	81	45
Mar 20, 1973	1	-	1 insect larva	93	-	16	14	-	6 *Glycinde*	6	129
Apr 5, 1973	6	-	3 insect larva 1 Collembola	10	-	97	23	-	3 *Eteone* 4 *Glycinde*	8	137
May 3, 1973	6	2	6 insect larva	78	6	42	2	8	8 *Eteone*	27	144
June 3, 1973	7	1	1 larva 1 mussel	2	6	39	12	23	1 *Eteone* 13 *Glycinde* 2 *Potamella*	32	98
July 14, 1973	1	135 young	3 medusa 10 insect larva 5 mussels 5 snails	24	5	47	1	38	1 *Eteone* 1 *Glycinde* 1 *Haploscoloplos* 1 *Potamella*	28	119
Aug 1, 1973	2	5 181 young	4 insect larva 11 mussels	46	1	42	3	14	1 *Eteone* 3 *Glycinde* 9 *Potamella*	15	119
Sept 15, 1973	5	2	3 snails 1 insect larva	3	-	17	4	-	1 *Eteone* 2 *Glycinde* 1 *Haploscoloplos*	5	28
Nov 10, 1973	5	2	-	-	1	1	-	1	-	-	3
Dec 8, 1973	3	3	1 insect larva	1	1	15	-	-	1 *Eteone* 1 *Glycinde* 1 *Potamella*	-	20

TABLE 40 (Continued)

MEAN DENSITIES OF OTHER FAUNA PER 10 CM^2 FROM AN INTERTIDAL SAMPLING STATION AT MINERAL CREEK

Date of Sample	Flat-worms	*Macoma balthica*	Other Larvae	Unknowns	Polychaetes					Frags.	Total
					Exogone	*Polydora*	*Capitella*	*Tharyx*	Others		
Jan 7, 1974	-	1	1 insect larva	1	3	5	-	-	2 *Eteone* 1 *Glycinde* 1 *Potamella*	1	13
Mar 26, 1974	-	1	4 mussels	1	1	1	5	13	1 *Glycinde*	1	22
Apr 24, 1974	-	2	1 insect larva 3 mussels	12	2	1	3	15	1 *Glycinde* 1 *Haploscoloplos*	-	35
May 22, 1974	-	6	2 mussels	30	-	-	-	-	2 *Potamella*	-	32
June 24, 1974	-	-	1 pycnogonid	-		NONE RECORDED					
July 24, 1974	-	-	-	-		NONE RECORDED					

TABLE 41

MEAN DENSITIES OF OTHER FAUNA PER 10 CM^2 FROM TWO INTERTIDAL SAMPLING STATIONS AT 0.0 METERS, BASELINE AND ALTERNATIVE STUDY BEACHES, ON ISLAND FLATS, PORT VALDEZ, ALASKA

Date of Sample	Flat-worms	*Macoma balthica*	Other Larvae	Unknowns	*Exogone*	Polychaetes *Polydora*	*Capitella*	*Tharyx*	Others	Frags.	Total
a. baseline beach											
July 29, 1972	-	-	-	-	-	-	-	-	-	-	0
Nov 5, 1972	-	-	2 insect larva	8	1	-	1	-	1 *Glycinde*	-	11
Apr 4, 1973	4	2	1 insect larva	6	2	1	-	-	1 *Eteone*	2	10
May 4, 1973	2	-	2 insect larva 2 hydroids 1 jellyfish	13	1	-	-	-	2 *Eteone*	-	16
June 2, 1973	10	1	2 insect larva 1 mussel	2	16	-	-	-	2 *Eteone* 2 *Glycinde*	2	22
June 29, 1973	1	19	1 snail 3 insect larva 2 mussels	1	13	3	1	-	3 *Eteone* 1 *Glycinde*	7	22
July 4, 1973	26	1 399 young	4 insect larva 2 mussels	10	107	-	-	2	1 *Eteone* 2 *Glycinde* 3 *Potomella*	3	125
July 29, 1973	17	441 young	11 insect larva 6 mussels	17	39	4	1	-	2 *Eteone* 4 *Glycinde* 1 *Haploscoloplos* 1 *Potamella*	1	69
Sept 14, 1973	-	-	-	-	3	1	-	-	-	-	4
Nov 11, 1973	2	8	3 insect larva 2 mussels	-	-	-	-	-	1 *Glycinde*	-	1
b. alternative beach											
July 29, 1972	-	-	1 scyphozoan	2	-	-	-	-	-	-	2
Nov 5, 1972	-	-	-	3	-	-	-	-	-	-	3

TABLE 42

MEAN DENSITIES OF OTHER FAUNA PER 10 CM^2 FROM AN INTERTIDAL SAMPLING STATION AT 0.0 METERS, OLD VALDEZ, PORT VALDEZ, ALASKA

Date of Sample	Flat-worms	*Macoma balthica*	Other Larvae	Polychaetes						Frags.	Total
				Unknowns	*Exogone*	*Polydora*	*Capitella*	*Tharyx*	Others		
July 26, 1972	7	-	1 insect larva 39 cypris larva	63	-	-	-	-	-	9	63
Mar 10, 1973	5	-	2 insect larva 1 cypris larva	-	-	-	-	-	-	-	-

TABLE 43

MEAN DENSITIES OF OTHER FAUNA PER 10 CM^2 FROM AN INTERTIDAL SAMPLING STATION AT 0.0 METERS, GALENA BAY, PORT VALDEZ, ALASKA

Date of Sample	Flat-worms	*Macoma balthica*	Other Larvae	Polychaetes						Frags.	Total
				Unknowns	*Exogone*	*Polydora*	*Capitella*	*Tharyx*	Others		
Nov 11, 1972	-	-	-	1	-	-	-	-	-	-	1
Jan 21, 1973	6	-	-	10	-	-	-	-	-	3	10
Feb 22, 1973	36	-	-	216	-	-	-	-	-	-	216
Nov 9, 1973	-	1	2 mussels	-	2	-	-	-	-	-	2

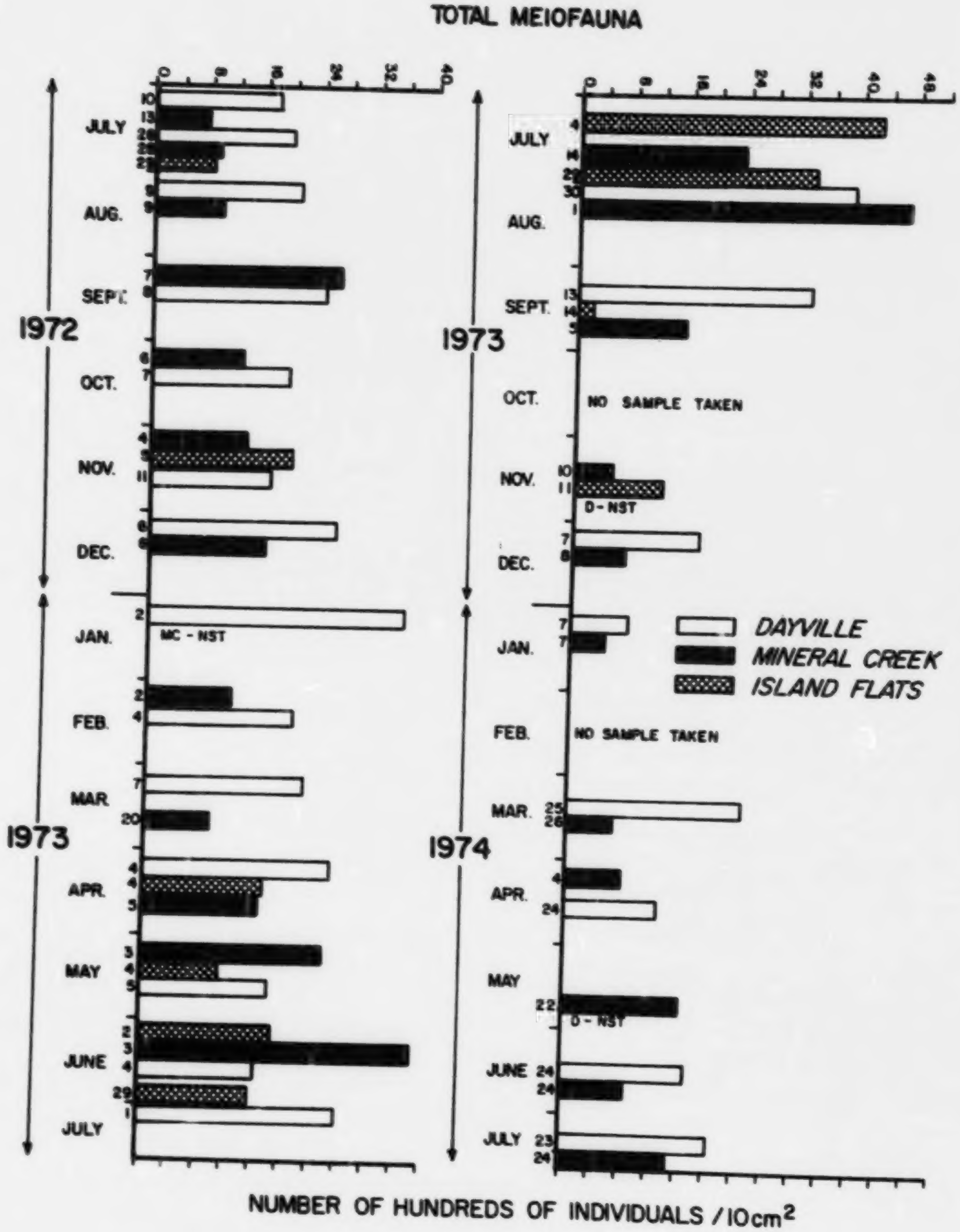

Figure 6. Seasonal variations of meiofauna from 0.0 m at all baseline sampling sites, Port Valdez. Island Flats sampled sporadically; see Tables 20, 26, 31, 36 and 41 for sampling dates. MC-NST = Mineral Creek, no sample taken. D-NST = Dayville, no sample taken.

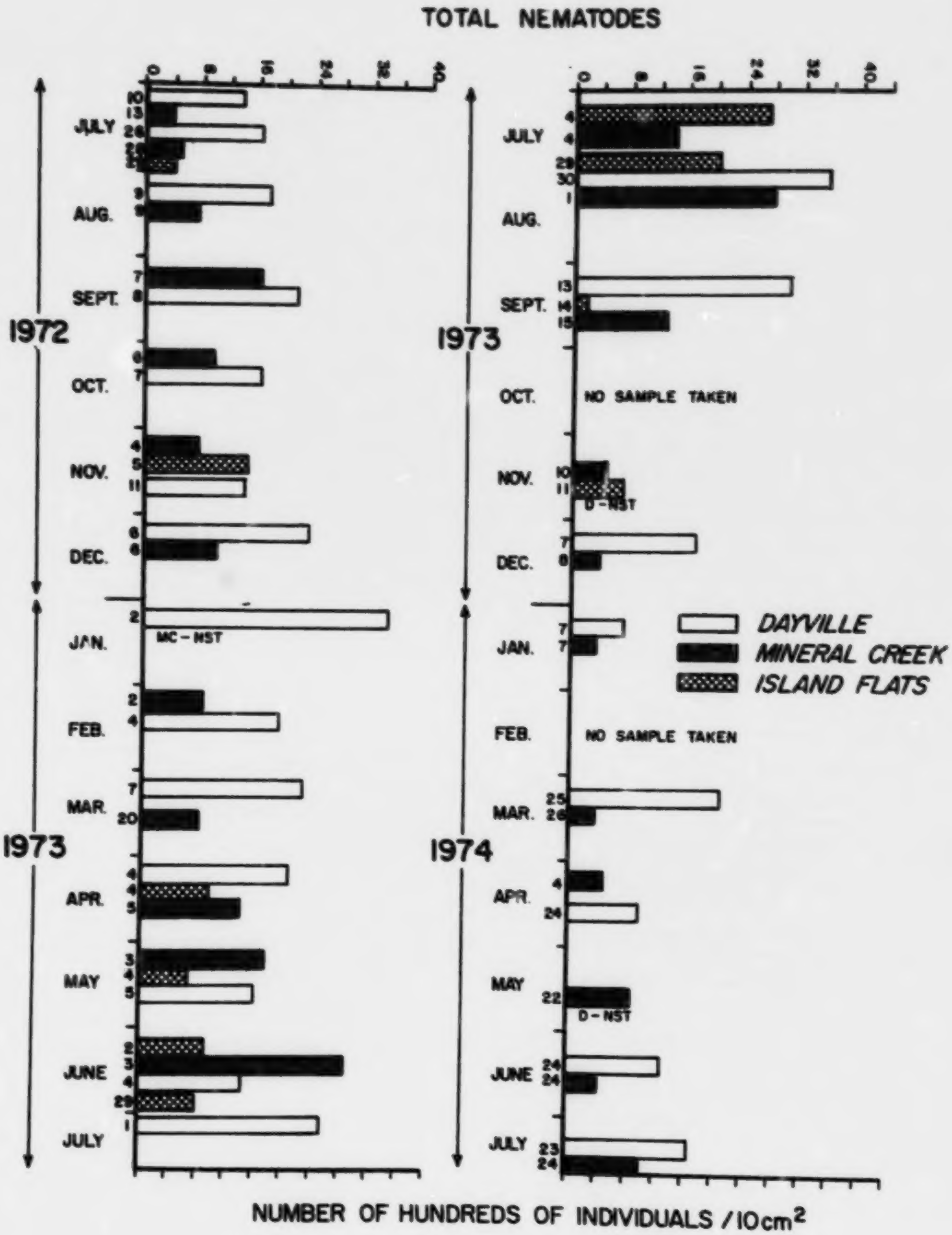

Figure 7. Seasonal variations of Nematodes from 0.0 m at all the baseline sampling sites, Port Valdez.

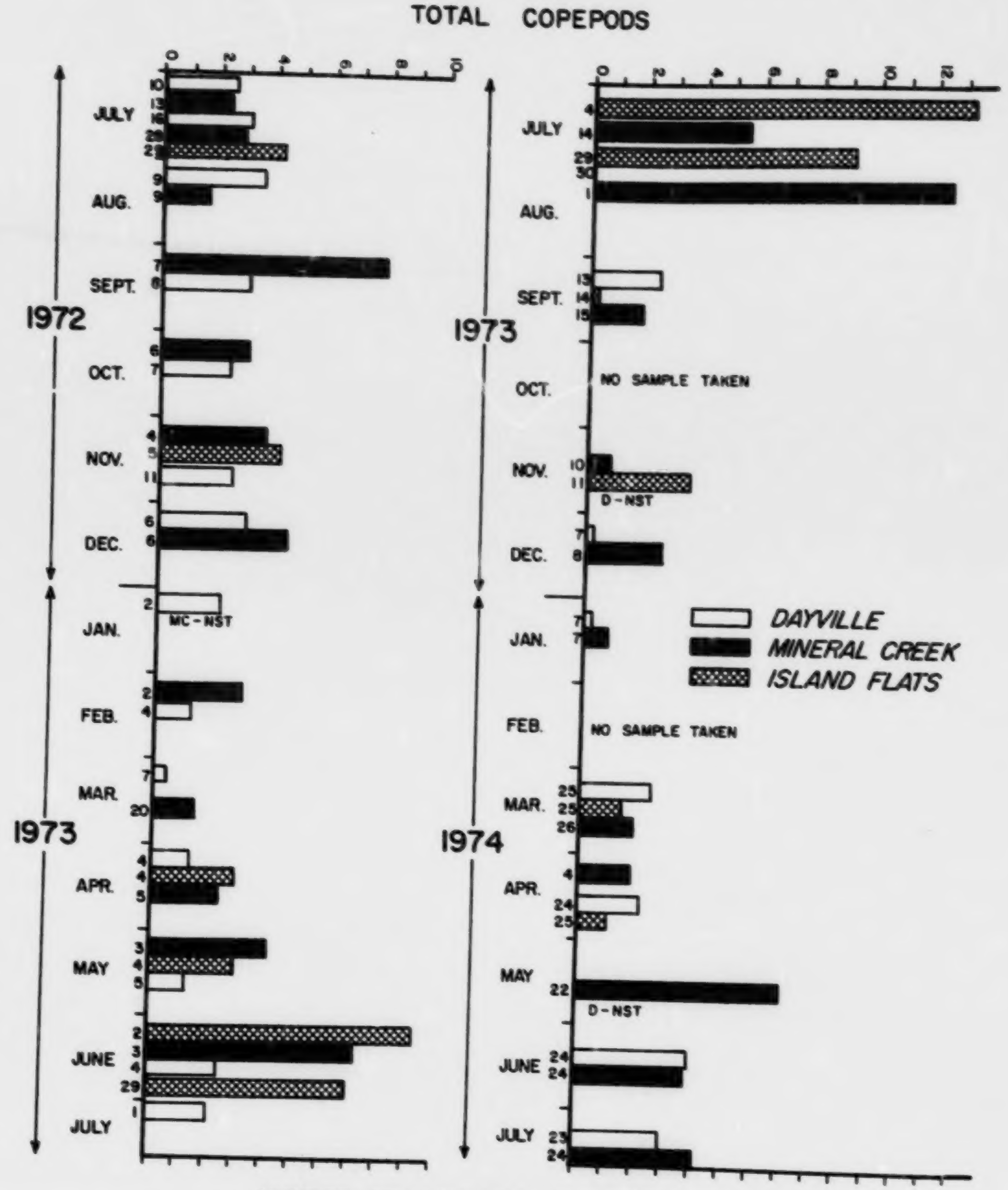

Figure 8. Seasonal variations of Copepods 0.0 m at all the baseline sampling sites, Port Valdez.

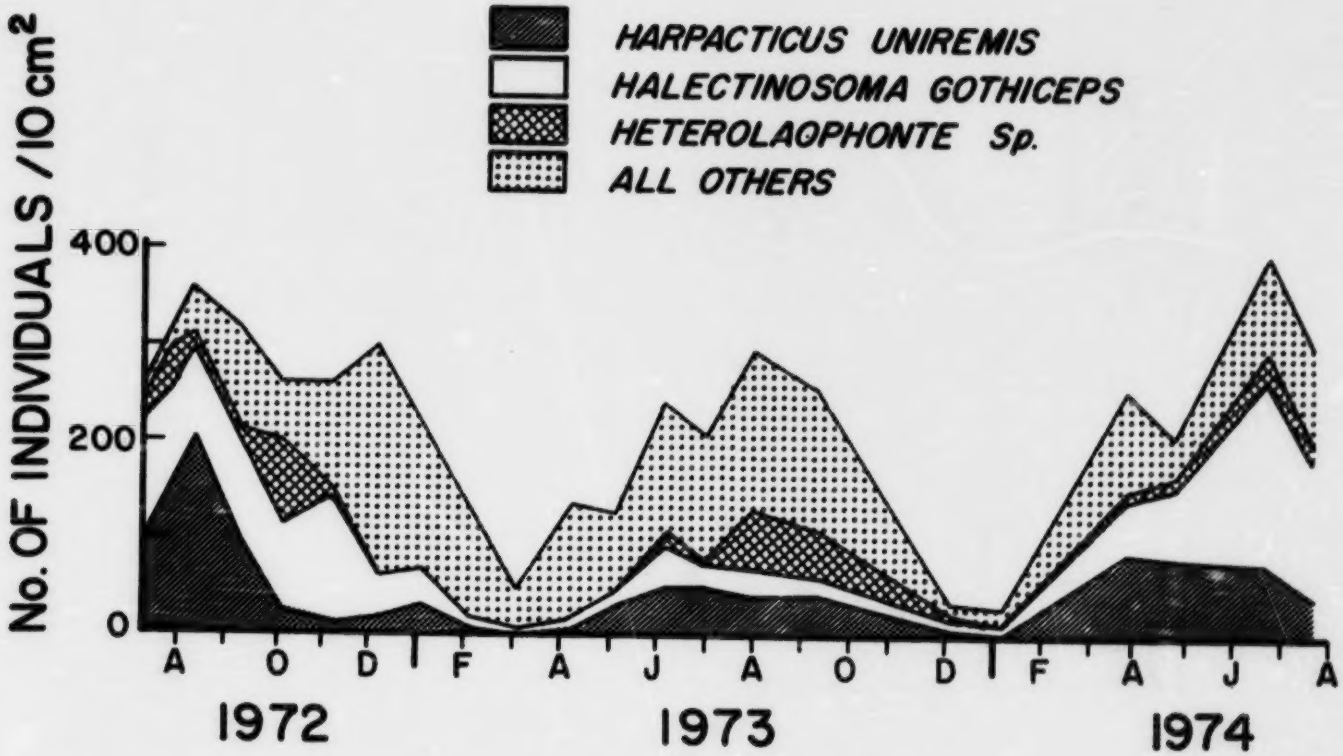

Figure 9. The cumulative percentages of numbers of copepods collected at the baseline site at Dayville, Port Valdez.

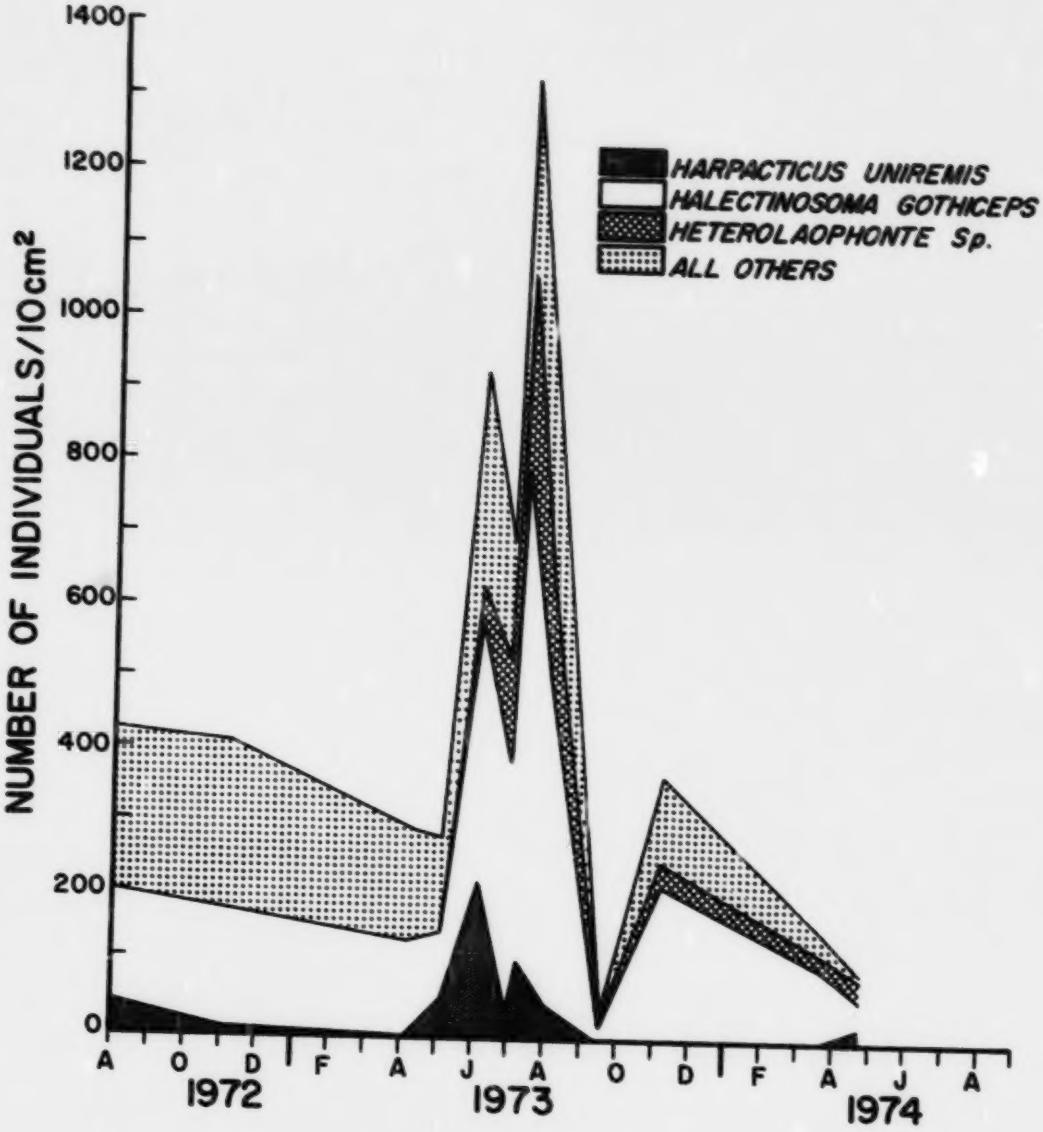

Figure 10. The cumulative percentages of numbers of copepods collected at the baseline site at Island Flats, Port Valdez.

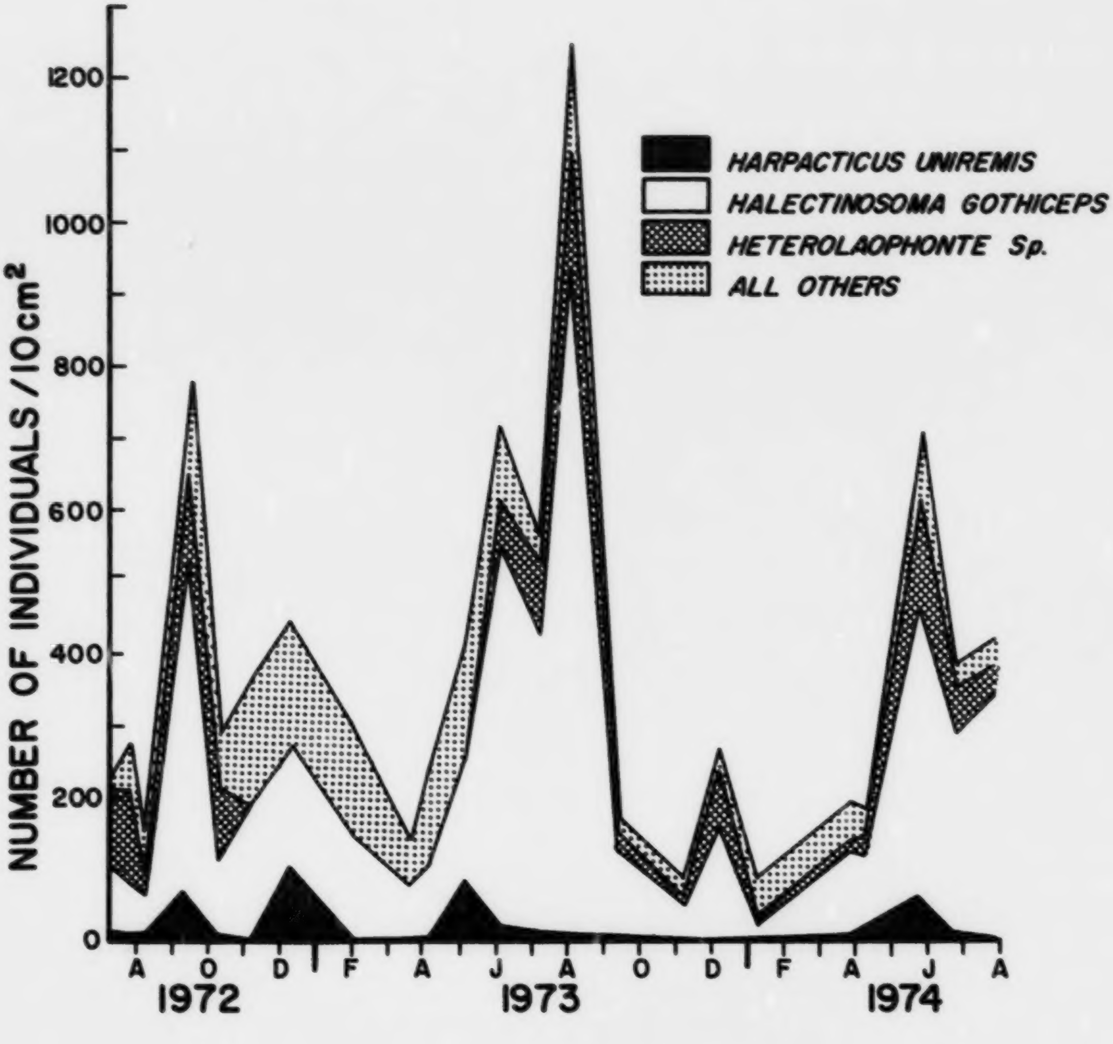

Figure 11. The cumulative percentages of numbers of copepods collected at the baseline site at Mineral Creek, Port Valdez.

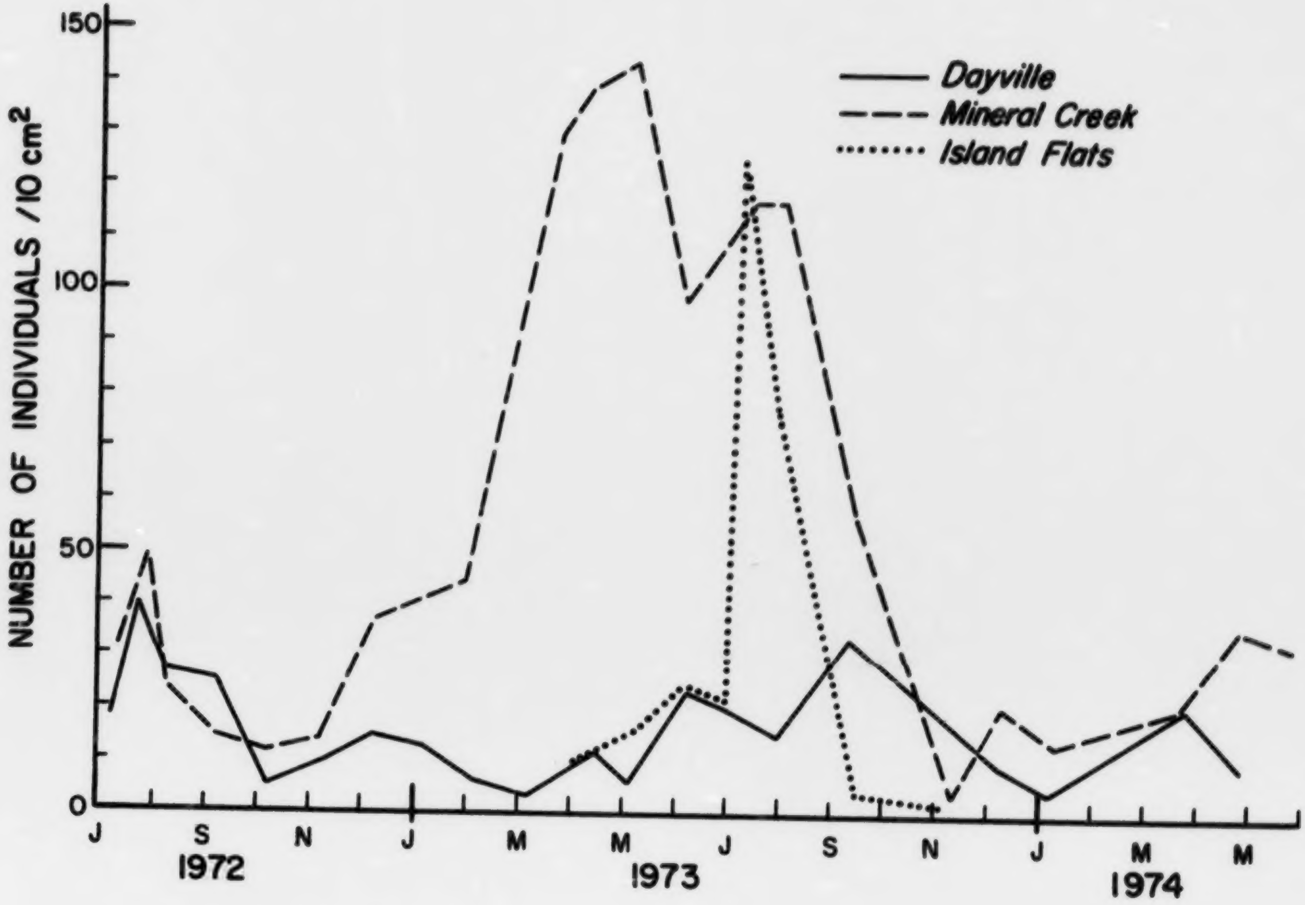

Figure 12. The number of polychaetous annelids collected monthly at the three baseline sampling sites in Port Valdez.

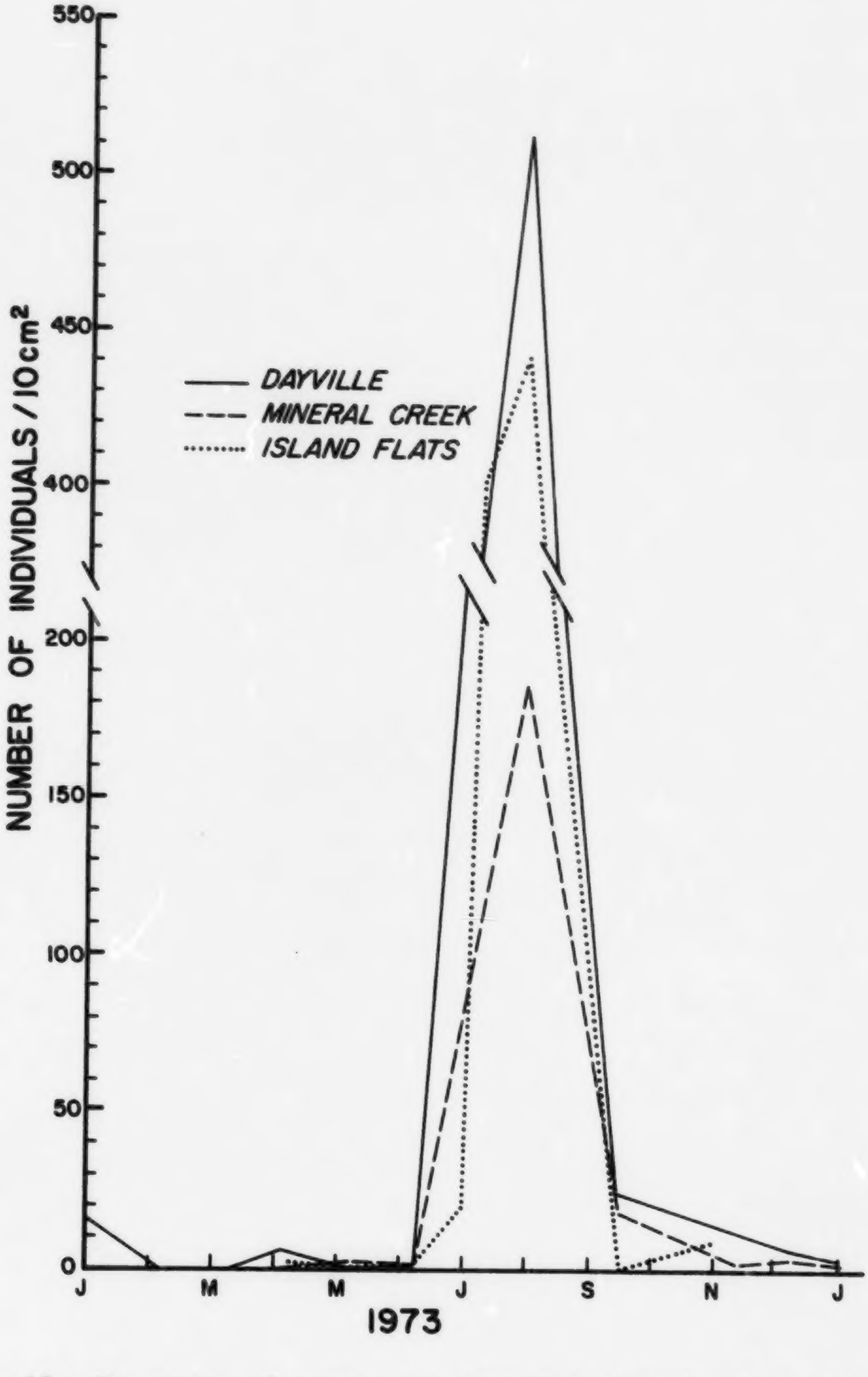

Figure 13. The number of young clams (*Macoma balthica*) collected monthly at the three baseline sampling sites in Port Valdez.

of tardigrade, *Hypsibius appelloefi*, was collected at Mineral Creek Flats, Island Flats, Old Valdez and Galena Bay Flats.

In addition, juvenile stages (frequently meiofaunal in size) of nine species of macrobenthic polychaetes were also encountered in samples. The small, black macrofaunal opisthobranch *Aglaja* sp. was occasionally taken in cores; this species was common on Dayville Flats, Old Valdez and Island Flats in late spring and throughout most of the summer. In the spring this mollusk and its gelatinous egg masses were widely dispersed over the flats.

Nematodes comprised 85.8% of the total number of organisms present on Dayville Flats, 65.8% in Mineral Creek Flats and 60.7% on the Island Flats Baseline Beach. Harpacticoid copepods were next in importance on the three beaches with values of 10.0%, 24.3% and 30.8% of the total meiofaunal organisms on each beach respectively. Total meiofaunal density per 10 cm^2 on each of the study beaches over the year was as follows - Dayville: 802 to 3875 individuals with a mean of 2205; Mineral Creek: 442 to 4682 with a mean of 1534; Island Flats Baseline Beach: 209 to 4243 with a mean of 1807. Nematodes ranged from 762 to 3426 individuals per 10 cm^2 at Dayville Flats with a mean of 1892, from 307 to 2849 on Mineral Creek Flats with a mean of 1010, and from 172 to 2682 on the Island Flats Baseline Beach with a mean of 1096. Copepods ranged from 26 to 387 individuals per 10 cm^2 on Dayville Flats with a mean of 221; from 83 to 1248 on Mineral Creek Flats with a mean of 373; from 29 to 1329 on the Island Flats Baseline Beach with a mean of 484 (see Tables 18 through 22 for summarization of data).

Interstitial protozoans and metazoans were rare.

Vertical Distribution

Most of the organisms were restricted to the upper three centimeters of sediment (e.g., Dayville Flats: July 1972-97.4% present; September 1972-96.2% present; January 1973-94.5% present; April 1973-97.8% present; see Table 44 for other study beaches). In cores taken to a depth of 8 cm, it was rare to encounter meiofaunal organisms below 5 cm; occasional nematodes were found. No seasonal differences in vertical distribution were noted on any of the study beaches (Table 44).

TABLE 44

VERTICAL DISTRIBUTION OF TOTAL MEIOFAUNA IN THE SEDIMENTS. EACH VALUE REPRESENTS THE MEAN OF FIVE CORES PER 10 CM^2.

Depth (cm)	Number of Individuals	Percent of Total	Number of Individuals	Percent of Total	Number of Individuals	Percent of Total	Number of Individuals	Percent of Total
a. Dayville	7/26/72		9/8/72		1/2/73		4/4/73	
1	972	50.4	1441	59.5	2142	58.4	1762	66.3
2	749	38.8	610	25.2	920	25.1	702	26.4
3	158	8.2	278	11.5	404	11.0	136	5.1
4	35	1.8	53	2.2	149	4.1	50	1.9
5	14	0.7	39	1.6	54	1.5	7	0.3
Total	1928	100.0	2421	100.0	3669	100.0	2657	100.0
b. Mineral Creek	7/28/72		9/7/72		2/5/73		4/5/73	
1	404	48.2	1655	62.8	696	57.6	769	46.7
2	246	29.3	733	27.8	329	27.2	518	31.5
3	94	11.2	150	5.7	78	6.5	222	13.5
4	59	7.0	66	2.5	62	5.1	98	6.0
5	36	4.3	31	1.2	43	3.6	38	2.3
Total	839	100.0	2635	100.0	1208	100.0	1645	100.0
c. Island Flats	7/29/72		11/5/72				4/4/73	
1	730	85.1	1545	77.4	No Sample Available		1522	90.9
2	97	11.3	333	16.7			107	6.4
3	18	2.1	56	2.8			22	1.3
4	10	1.2	43	2.2			13	0.8
5	3	0.3	20	1.0			10	0.6
Total	858	100.0	1997	100.0			1674	100.0

Seasonal Fluctuations in Density

Regular monthly sampling at three sites provided information on seasonal changes in the meiofauna. The data are included in Tables 18 through 43 and Figures 6 through 13, and are reported separately here for each study beach.

Dayville Flats: Densities for total meiofauna during the first year of the investigation (July 1972 through June 1973) were lowest in early July with 1636 individuals per 10 cm^2. The numbers increased to a peak of 2421 individuals in September followed by a decline through November. During January, 3669 organisms per 10 cm^2 were recorded; this was the highest value for the first year. A decrease in numbers then took place, followed by another peak of 3875 individuals in July of the second year of investigation. The latter density value was the highest recorded for the two-year period of investigation. The peak densities for each year are primarily a reflection of nematode abundance. Large numbers (513/10 cm^2) of a temporary meiofaunal species, *Macoma balthica*, occurred in the July 30, 1973 sample. Similar increases in numbers of this clam for the summers of 1972 and 1973 are reported for Dayville by R. Myren (personal communication; National Marine Fisheries Service Baseline study). An overall increase in density of some of the harpacticoid species took place in the winter of 1972 and summer of 1974 (Tables 29 through 31), but most species reached their abundance peaks in late summer and early fall. No clearcut trends can be noted in number of polychaetes taken, but a general increase in numbers in the summer is apparent. Insect larvae were collected in samples throughout the year. Meiofaunal peaks, in general, occurred during periods of highest water and sediment temperatures (Figures 4 through 8). Water temperatures were somewhat higher in the winter of 1972 and 1973 than that recorded for the winter of 1973 and 1974, and meiofaunal increases occurred in the former period even though organisms were subjected to freezing conditions at low-tide exposure (Figures 4 and 5).

Mineral Creek: Densities for total meiofauna during the first year of the investigation (July 1972 through June 1973) were lowest in early July with 656 individuals per 10 cm^2. The numbers increased to a peak of 2635 individuals in September followed by a decline through November. During

December, an increase to 1625 individuals per 10 cm^2 recorded. Weather conditions prevented collection of a January sample. A decrease in numbers then took place followed by a peak in June (3862 individuals) with another larger peak in August (4682 individuals). The latter value represented the greatest density recorded at any of the stations during the two-year study period. As in the Dayville study site, the high densities were primarily a reflection of nematode abundance. However, increases in numbers of the copepod *Halectinosoma gothiceps* in September 1972 and June and August 1973 also contributed to abundance peaks at these times. Only a few copepod species showed density maxima in summer. No clearcut trends in polychaete densities occurred, although some spring and summer increases took place. Large numbers of recently settled *Macoma balthica* were collected in July and August 1973. All other meiofaunal species demonstrated erratic changes in density with no obvious trends. Insect larvae were collected throughout the year. Meiofaunal peaks, in general, occurred during periods of highest water and sediment temperatures (Figures 4 and 5). An increase in numbers of meiofauna occurred in December 1972 at the time of lowest water and sediment temperatures for the year.

Island Flats: Logistics problems resulted in a reduced sampling schedule for this area. Two beach sites were initially sampled, but one beach (Baseline Beach) was ultimately selected for baseline counts and experimental-oil addition studies (Sections VIII, IX, X and XI). An alternative beach was sampled periodically when time permitted.

The initial density of all meiofauna recorded for July 1972 was 858 organisms per 10 cm^2. No additional samples were taken until November 1972 at which time the density was 1997 individuals per 10 cm^2. Slightly lower densities were recorded at the next four sampling periods. The highest meiofaunal count for the year occurred on 4 July 1973 when 4243 individuals were counted. The numbers of meiofauna remained high throughout July and then dropped precipitously in September. Numbers, as reflected by copepods only, began to increase again in the spring of 1974. The high-density peaks throughout the sampling period were primarily a reflection of nematode abundance, although a large increase of copepods, mainly *Halectinosoma gothiceps*, occurred simultaneously with nematode increments during the July 1973 surge in meiofaunal density. Increases in Foraminifera, flatworms, polychaetes, ostracods, cumaceans, mites and young *Macoma balthica* were also noted in July 1973. *Protohydra* and insect larvae occurred throughout the year. The July 1973 meiofaunal peaks coincided with periods of highest water and sediment temperatures (Figures 4 through 8).

Meiofaunal collections made at Old Valdez and Galena Bay were sporadic, and data collected here are only useful as the basis for development of future monitoring programs in the areas.

Reproductive Biology of Harpacticoid Copepods

Limited information on the reproductive biology of several harpacticoid copepod species was collected in conjunction with meiofaunal counting activities. Only one species, *Harpacticus uniremis*, was subjected to detailed analysis; it is treated in detail in Section VII. The months in which egg-bearing and copulating individuals of all copepod species were noted are summarized in Table 45. Although the data in Table 45 are not complete (with the exception of *H. uniremis*; see Section VII), they represent preliminary indications of sensitive periods in the life histories of the species involved. It is apparent that the washing process employed to separate meiofauna from sediment also removed egg clutches from females and pulled apart copulating individuals. However, the limited data does emphasize the fact that many of the harpacticoid species carry eggs through the winter and that larvae are released no later than midsummer. Only one species, *Halectinosoma gothiceps*, appears to be actively reproducing throughout most of the year. The relatively high densities of this species at all of the Baseline study sites for all collection periods also reflect the continuing reproductive activity; however, densities are somewhat reduced in midwinter. Peak densities for *H. gothiceps* far exceeded that counted for any other individual copepod species (Tables 24 through 28). Coull and Vernberg (1975)[43] report that dominant meiobenthic harpacticoid copepods studied in South Carolina appear to be in a reproductive state all year round whereas less abundant species have distinct reproductive periods. Examination of our data indicates a similar situation (Tables 24 through 33 and Table 45). Coull and Vernberg (1975)[43] found *Microarthridion littorale* to be abundant and ovigerous

TABLE 45

REPRODUCTIVE BIOLOGY OF THE COMMON COPEPOD SPECIES ON BEACHES IN PORT VALDEZ, ALASKA.
DATA POOLED FOR THE YEARS 1972-1975: E = EGG-BEARING INDIVIDUALS:
C = COPULATING INDIVIDUALS.

Copepod Species	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	COMMENTS
Harpacticus uniremis	E,C	E,C	E,C	E,C	E,C	0	0	0	0	0	0	E,C	
Nannopus palustris	E	–[a]	–	–	–	E	–	C	–	–	–	E	
Mesochra pygmaea	–	–	–	E	E	–	–	–	–	–	–	–	no copulation observed
Halectinosoma gothiceps	E	E	E,C	E,C	E,C	E,C	E,C	E,C	E,C	0	0	E	
Halectinosoma finmarchicum	E	E	E	–	E	0	0	0	0	0	0	0	no copulation observed
Heterolaophonte sp.	0	0	E	E	E	E,C	E	0	0	0	0	0	
Type 11	E	E	E	E	E	E	0	0	0	0	0	E	no copulation observed
Microarthridion littorale	E	E	E	0	E	E	E	0	0	0	0	0	no copulation observed

[a] Dash represents: no data.

throughout the year. This species was not abundant in Port Valdez, and appears to have a seasonal reproductive period (Tables 29 through 33; Table 45).

DISCUSSION

The intertidal sediment-dwelling meiofauna and some macrofaunal species of Port Valdez have been examined over a two-year period, and the former group of organisms has been shown to be relatively diverse in types as well as numbers of organisms present. The faunal abundance and general composition of the major taxonomic groups collected, in general, compare with that found for the few intertidal mudflats examined in north temperate regions (see McIntyre, 1969[36] for review of work elsewhere). No published work for mudflats at latitudes similar to Port Valdez is available, however, an intensive investigation of the interstitial fauna of sandy beaches of northern Norway is available (Schmidt, 1972)[44]. Although meiofaunal representatives of nine phyla were found in Port Valdez, species with adaptations for an interstitial way of life were uncommon (see Swedmark, 1964[45] for review of interstitial faunal adaptations). Ciliate protozoans, common to sediment beaches elsewhere, were rarely observed in freshly extracted Port Valdez sediments, and those few observed did not appear to be interstitial types (unpublished data). Turbellarian flatworms, although not common, were observed in fresh sediments of all beaches investigated, but only a few of the species showed features typical of interstitial forms (Swedmark, 1964)[45]. Presumably the fine sediments characteristic of the Port Valdez beaches investigated selected against an interstitial way of life in favour of burrowing activity for species present.

Nematodes were the most abundant organisms encountered, with harpacticoid copepods second in overall abundance. Similar observations of copepod abundance have been made on sediment shores elsewhere (Norway: Schmidt, 1972[44]; Denmark: Fenchel *et al.*, 1967[46]; Muus, 1967[41]; Straarup, 1970[47]; British Isles: Barnett, 1968[35]; Harris, 1972[48]; McIntyre and Murison, 1973[40]). The copepods species observed in Port Valdez appeared to be primarily burrowing rather than the interstitial types.

Since little information is available for meiofaunal densities of north temperate or subarctic intertidal mudflats, comparison with other areas is difficult. However, in England, Barnett (1968)[35] observed harpacticoid densities ranging from 100 to 1021 individuals per 10 cm^2, and Capstick (1959)[49] reported 228 to 2830 nematodes per 10 cm^2 in the Blyth Estuary in England. Rees (1940)[50] recorded 70 to 10,440 nematodes, 0 to 500 copepods, and 90 to 11,820 total meiofaunal organisms per 10 cm^2 on a mudflat of the Bristol Channel in England. In the present study, harpacticoid copepod densities ranged from 26 to 1329 individuals per 10 cm^2, nematodes from 172 to 3496 per 10 cm^2, and total meiofauna from 209 to 4682 individuals per 10 cm^2.

In soft deposits meiofauna generally occurs in the upper few centimeters (Barnett, 1968[35] for review; Tietjen, 1969[51]; McIntyre, 1969[36]; Rees, 1940[50]), and it is suggested that restriction of copepods to the upper layers may be due to a lack of oxygen which is generally considered to be absent below 1 cm (Barnett, 1968[35]; McIntyre, 1969[36]). The majority of meiofaunal organisms in Port Valdez occurred in the upper three centimeters; below this depth only small numbers of nematodes were typically encountered. Dissolved oxygen in interstitial waters in Port Valdez sediments was only detected in the upper three centimeters of sediment (Section IV). It is probable that the presence of an anoxic environment in the subsurface sediments restricts meiofaunal organisms primarily to the surficial sediments in Port Valdez.

The three major study areas chosen for examination differ somewhat in physical (Section IV) and biological (Sections V, VII, XI, and this chapter) characteristics, although generalizations concerning common processes operating in all of the areas can be made. Some of the differences in meiofaunal composition (species content and numbers of individuals of each species) appear to be related to the sediment characteristics of each area (see Section IV for discussion of sediment properties of the study areas). Thus, the somewhat coarser sediments of the sampling sites at Mineral Creek and Island Flats harbor a greater percentage of harpacticoid copepods as well as a greater number of individuals of each species than that found in the finer sediments of Dayville Flats; nematodes were the more successful meiofaunal organisms in the latter area (Tables 18 through 22). Of the three species of copepods (*Halectinosoma gothiceps*, *Heterolaophonte* sp., and *Harpacticus uniremis*) chosen as monitoring organisms for the oil experiments conducted on Island Flats (see Section X for discussion of experiment), *Halectinosoma gothiceps* was the most successful species collected in the baseline collections in this study area (Table 26); it was also very common in the other two baseline study beaches (Tables 24 and 25). *Heterolaophonte* sp. was successful at Island Flats and Mineral Creek. *Harpacticus uniremis* appears to be most successful at Dayville and Island Flats. The latter species is found on all of the sediment beaches examined in Port Valdez, and is primarily restricted to the intertidal flats with relatively few individuals occurring in the shallow subtidal (see Section VII for an account of this species in Port Valdez).

Foraminifera were most abundant in the more coarse sediments of Mineral Creek, and were essentially absent in the fine sediments of Dayville. The cnidarian polyp *Protohydra* sp., although never very common, was about equally abundant in all of the study areas with sporadic increases of density recorded during the study period. *Protohydra leukharti* feeds on harpacticoid copepods on sediment beaches in Denmark, and its fluctuations in abundance there are related to fluctuations in the density of harpacticoid copepods on these beaches (K. Muus, 1966[52]; B. Muus, 1967[41]). The presence or absence of *Protohydra* sp. in Port Valdez sediment beaches may likewise be related to the availability of selected copepod-food species.

In general, on temperate intertidal mudflats, little or no seasonal changes in vertical distribution of meiofauna occur (Barnett, 1968[35]; McIntyre, 1969[36]). This was also true for the Alaskan mudflats described in this chapter where most of the organisms were restricted to the upper three centimeters of sediment at all seasons of the year. As indicated above, oxygen deficiency below this depth presumably deters deeper vertical incursions of the meiofaunal organism into the sediment; the restrictive features of oxygen in meiofaunal vertical distribution has likewise been suggested by Barnett (1968)[35] for an English mudflat.

Interstitial salinities measured by Barnett (1968)[35] on an exposed mudflat, showed considerable reductions in salinity during periods of heavy rain, but were never less than 18.2 °/₀₀. Conversely, conditions of warm sun and strong breezes produced interstitial salinity increases on the exposed mudflat. Interstitial salinities in Port Valdez fluctuated throughout the study period, but typically occurred at values higher than that recorded for adjacent tidal waters (Section IV). Interstitial salinities were never lower than 16 °/₀₀ during the study period; this salinity is close to the value suggested as a lower limit of tolerance for most marine species that might penetrate estuaries (Barnes, 1974)[18]. The sediment-dwelling harpacticoid copepods of Port Valdez cannot tolerate the very low salinities characteristic of overlying waters there during the spring and summer (see Section IV and Hood *et al.*, 1973[1] for salinity data), and will die rapidly if exposed to salinities less than 5 °/₀₀ (Feder, unpublished observations). Thus, the relative stability of the interstitial salinity of the surficial sediments in Port Valdez makes survival possible here; alteration of intertidal sediments by industrial activity could alter the salinity-stability characteristics of the sediments with resultant loss of intolerant species in the area (see Barnes, 1974[18] for review; Leppäkoski, 1968[19]).

The high winter meiofaunal densities recorded for Dayville Flats in the winter of 1972 and 1973 have not been previously reported for north temperate or sub-arctic intertidal areas. Investigations of intertidal meiofauna along the British and Scandinavian coasts have shown that densities are normally lowest during the winter months. In Denmark, Muus (1967)[41] noted little seasonal fluctuation in the number of nematodes although summer decreases occurred. He reported a spring maximum for harpacticoid copepods in the same area. Harris (1972)[48] working on a sand beach in England observed high meiofaunal densities in summer and fall, and low densities from December to March. In Scotland the meiofaunal populations of an intertidal sand area during September were two to three times that of winter levels (McIntyre and Murison, 1973)[40]. In the Danish Waddensea, nematodes and harpacticoids were least abundant during the winter and most abundant in June (Smidt, 1951)[53]. Seasonal examination of subtidal meiofauna on a soft bottom along the Swedish west coast demonstrated a maximum abundance of organisms (nematodes, kinorhynchs, ostracods, harpacticoid copepods) in the autumn (Nyholm and Olsson, 1973)[54].

Smidt (1951)[53] suggested that freezing temperatures may have catastrophic effects on intertidal meiofaunal populations. However, the high meiofaunal densities on the Dayville mudflat corresponded with sub-zero air temperatures and frozen surface sediment in the winter of 1972 and 1973. Barnett (1968)[35] working in England demonstrated the survival of two species of harpacticoids frozen at -9.0°C for 9 hours, and he theorized that freezing temperatures would not seriously affect populations of those copepods. It would appear that Barnett's comments also apply to the intertidal meiofauna of Port Valdez but that the number of surviving organisms during the cold season here varies from year to year.

It is possible that the high-winter meiofaunal densities observed for Dayville Flats and Mineral Creek in the winter of 1972-73 (Tables 18, 19, 29 and 30) are not typical of long-term annual meiofaunal variations in Port Valdez. The low densities of meiofaunal species noted for all study beaches in the following winter are more typical of findings on northern beaches elsewhere (see above discussion). The somewhat higher water temperatures recorded in Port Valdez during the winter of 1972 and 1973 may represent a partial explanation for the high-winter densities at this time. A subtidal meiofaunal investigation in the Mediterranean by de Bovée and Soyer (1974)[55] likewise demonstrated winter increase in all organisms examined. These authors reported slight increases in water temperatures during this period, and also suggested that the increase in meiofaunal numbers might be due to unusually favourable conditions. On the other hand, Coull (1970)[56] reported a maximum abundance of nematodes and one species of harpacticoid copepod in a shallow subtidal area on the Bermuda platform during a period with minimum water temperatures for the year. He suggests that the abundant forms were the only ones able to cope with the alterations in the habitat during the winter. An explanation for meiofaunal fluctuations in Port Valdez can best be resolved with further sampling in the area to determine seasonal variations over a long-time base.

SECTION VII

BIOLOGY OF THE HARPACTICOID COPEPOD, *HARPACTICUS UNIREMIS* KRÖYER ON DAYVILLE FLATS, PORT VALDEZ

INTRODUCTION

Harpacticoid copepods are conspicuous members of the sediment meiofauna of Dayville Flats, Port Valdez (Section IV, Figure 1), and *Harpacticus uniremis* Kröyer, a relatively large (total length up to 1.5 mm) olive-green copepod, is one of the most obvious of the species present. Although Sars (1904)[57] originally described *H. uniremis* as a subtidal species found only on muddy bottoms ranging from 36 to 182 m in depth, Lang (1948[58], 1965[59]) more recently reported it as a widely distributed species of the North Pacific intertidal region. Little biological information is available for *H. uniremis* and nothing is known for the species in Alaska. A brief account of the nauplius and copepodite stages of *H. uniremis* is found in Brian (1919)[60], and Itô (1971)[61] includes preliminary biological studies of the copepod from Hokkaido, Japan as well as detailed descriptions of all copepodid stages. General information on benthic marine copepods is relatively limited, but a number of excellent papers are available for comparative field studies on a variety of species (Coull and Vernberg, 1975[43]; McIntyre, 1969[36]; and McIntyre and Murison, 1973[40]).

Port Valdez is an area for which little biological baseline data was available at the time of its selection as the marine terminus for a pipeline to transport oil from northern Alaska. It was with this data deficiency in mind that an investigation of the intertidal ecosystem of Port Valdez was initiated in 1972 (Feder, 1971)[62]. In view of a need for selection of species in Port Valdez that could be readily monitored, it became apparent early in the investigation that *Harpacticus uniremis* might be one species that could serve this need. A rather restricted reproductive period, indicated by initial qualitative studies, suggested that this copepod might demonstrate vulnerability to oil by way of anomalies in reproductive activities. Furthermore, the species is widely distributed on beaches in the area, and is readily identifiable. In addition, the seasonal occurrence of large numbers of salmon fry along the shores of Port Valdez suggests the possibility that *H. uniremis* might serve as a food for these fishes (see Kaczynski *et al.*, 1973[42] for data on use of harpacticoids as food by pink, *Oncorhynchus gorbuscha*, and chum, *O. keta*, salmon elsewhere; also see McIntyre and Murison, 1973[40]), and could represent an important trophic link for the young salmon here.

This section presents biological baseline data on the harpacticoid copepod *Harpacticus uniremis* from one sediment shore in Port Valdez, Dayville Flats. Aspects treated include growth, reproduction and density relationships.

METHODS

Preliminary exploratory surveys of the meiofauna of Dayville Flats in March through June of 1972 suggested that year-round sampling at a baseline site in the harsh environment of Port Valdez could best be accomplished at a mid-tide (0.0 m) location. Thus, most samples available to the investigation of *Harpacticus uniremis* are from the baseline site. In addition, two transects were sampled in order to examine the general distribution of *H. uniremis* on the tidal flat - one transect was occupied early in the investigation (July 1972) and the other was taken in the final year of the study (March 1975).

Copepod samples were obtained by three methods: (1) a qualitative sample was taken by means of a sediment sweep in May 1972, and copepods were removed from a small portion of the collected material; (2) individuals were quantitatively extracted monthly (July 1972 through January 1974) from the upper three centimeters of all of the available core (10 cm^2) taken from the Dayville Flats baseline sampling (see Section VI for details on sampling methodology); additional cores taken at this time were examined for reproductive work; (3) samples were taken monthly from a larger area (100 cm^2 plots to a depth of 2 cm) from March 1974 through May 1975 in order to increase the number of *Harpacticus uniremis* available for reproductive studies; typically three plots were examined each month. All copepods in each core or plot were counted.

All samples were preserved in 10% formalin and stained with Rose Bengal to facilitate sorting. All adult and copepodid specimens were removed and examined in the laboratory with a Wild dissection microscope.

Lengths used throughout this section were obtained by measuring cephalothorax length inclusive of the rostrum (Maly, 1973)[63]. Variable bending and telescoping of the body precluded accurate measurement of total length. At least 25% of those specimens found in each sample was measured. The growth of *Harpacticus uniremis* over a three-year period (May 1972 to May 1975) is described by analyzing monthly cephalothorax-length distributions.

Nauplii were not identified, but copepodites as small as 0.20 mm were determined. Males were easily distinguished from females by way of the antennal modification of the male for grasping the female (Itô, 1971)[61]. Small copepodites (Stages I-III) could not be sexed, but the sexes of all larger copepodites (Stages IV-V) were readily distinguishable. Copepodite sex ratios were examined in May 1972 and March 1974 when copepodites were most abundant.

The number of mating pairs (males grasping females) and gravid females (females with egg sacs) was counted. The number of eggs per sac was counted in a random sample of measured gravid females taken from the samples of March 1974 and February, March and April 1975. Length measurements were made on all egg sacs examined.

The transect data obtained on 27 March 1975 was compared using the Newman-Keuls multiple comparison test with equal sample sizes (Zar, 1974)[64]. Three 100 cm^2 plots were sampled at each of eight tidal levels.

GROWTH

Table 46 lists the monthly frequency of occurrence by number and percentage of copepodites, adult males and females at appropriate cephalothorax lengths. Copepodites were sexed when possible, and measured from samples taken from the two months demonstrating major abundance peaks of copepodites -- 15 May 1972 and 27 March 1974 (Table 47). Copepodites that could not be sexed ranged from 0.20 mm to 0.40 mm with a mean of 0.29 ± 0.5 mm. Copepodid males ranged from 0.32 mm to 0.46 mm with a mean of 0.41 ± 0.03 mm, and copepodid females ranged from 0.36 mm to 0.58 mm with a mean of 0.45 ± 0.04 mm. Length-frequency histograms for copepodites, and adults (males and females) are presented in Figure 14.*

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*Note: Continuation of text on page 143.

TABLE 46

MONTHLY FREQUENCY OF OCCURRENCE BY NUMBER AND PERCENT OF *HARPACTICUS UNIREMIS* COPEPODITES, ADULT MALES AND FEMALES AT APPROPRIATE CEPHALOTHORAX LENGTHS FROM MAY 1972 THROUGH MAY 1975

Cephalo-thorax length (mm)	Sample Dates															
	15 May 1972						10 July 1972		9 August 1972		8 September 1972					
	Copepodites		Adult Males		Adult Females		Adult Females		Adult Females		Copepodites		Adult Males		Adult Females	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
0.20	3	0.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.22	4	1.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.24	10	3.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.26	23	6.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.28	22	6.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.30	22	6.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.32	8	2.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.34	11	3.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.36	16	4.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.38	10	3.0	-	-	-	-	-	-	-	-	1	0.6	-	-	-	-
0.40	24	7.2	1	0.3	-	-	-	-	-	-	-	-	-	-	-	-
0.42	15	4.5	2	0.6	-	-	-	-	-	-	-	-	-	-	-	-
0.44	14	4.2	1	0.3	-	-	1	0.5	-	-	-	-	-	-	-	-
0.46	27	8.2	7	2.1	-	-	1	0.5	3	1.5	-	-	-	-	1	0.6
0.48	19	5.7	19	5.7	1	0.3	11	5.7	8	4.2	-	-	1	0.6	10	6.3
0.50	12	3.6	27	8.2	-	-	27	14.2	14	7.3	1	0.6	-	-	32	20.2
0.52	1	0.3	6	1.8	-	-	45	23.6	42	22.1	-	-	-	-	31	19.6
0.54	-	-	5	1.5	2	0.6	48	25.2	64	33.6	-	-	1	0.6	34	21.5

TABLE 46 (Continued)

MONTHLY FREQUENCY OF OCCURRENCE BY NUMBER AND PERCENT OF *HARPACTICUS UNIREMIS* COPEPODITES

	Sample Dates															
	15 May 1972						10 July 1972		9 August 1972		8 September 1972					
Cephalo-thorax length (mm)	Copepodites No.	Copepodites %	Adult Males No.	Adult Males %	Adult Females No.	Adult Females %	Adult Females No.	Adult Females %	Adult Females No.	Adult Females %	Copepodites No.	Copepodites %	Adult Males No.	Adult Males %	Adult Females No.	Adult Females %
0.56	-	-	-	-	7	2.1	28	14.7	26	13.6	-	-	-	-	29	18.3
0.58	1	0.3	-	-	6	1.8	19	10.0	15	7.8	-	-	-	-	9	5.7
0.60	-	-	1	0.3	-	-	5	2.6	13	6.8	-	-	-	-	8	5.1
0.62	-	-	-	-	1	0.3	5	2.6	5	2.6	-	-	-	-	-	-
0.64	-	-	-	-	1	0.3	-	-	-	-	-	-	-	-	-	-
0.66	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TOTALS	242	73.5	69	20.9	18	5.5	190	100	190	100	2	1.2	2	1.2	154	97.4
Mean length Cephalo-thorax	0.37		0.49		0.57		0.54		0.54		—		—		0.53	
Standard Deviation	0.09		0.03		0.03		0.03		0.03		—		—		0.03	

TABLE 46 (Continued)

MONTHLY FREQUENCY OF OCCURRENCE BY NUMBER AND PERCENT OF *HARPACTICUS UNIREMIS* COPEPODITES

Cephalo-thorax length (mm)	Sample Dates: 7 October 1972				8 November 1972						6 December 1972					
	Copepodites No.	Copepodites %	Adult Females No.	Adult Females %	Copepodite No.	Copepodite %	Adult Males No.	Adult Males %	Adult Females No.	Adult Females %	Copepodites No.	Copepodites %	Adult Males No.	Adult Males %	Adult Females No.	Adult Females %
0.20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.26	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.28	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.32	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.34	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.38	2	9.5	-	-	-	-	-	-	1	11.1	1	1.1	-	-	-	-
0.40	-	-	-	-	-	-	1	11.1	-	-	-	-	-	-	-	-
0.42	-	-	-	-	1	11.1	-	-	-	-	3	3.5	-	-	-	-
0.44	-	-	-	-	-	-	-	-	-	-	1	1.1	1	1.1	-	-
0.46	-	-	-	-	-	-	-	-	1	11.1	-	-	3	3.5	-	-
0.48	-	-	-	-	-	-	-	-	-	-	-	-	2	2.3	-	-
0.50	-	-	2	9.5	-	-	-	-	1	11.1	-	-	1	1.1	10	11.7
0.52	-	-	2	9.5	-	-	-	-	1	11.1	-	-	-	-	13	15.2
0.54	-	-	3	14.2	-	-	-	-	3	33.3	-	-	-	-	17	20.0
0.56	-	-	4	19.0	-	-	-	-	-	-	-	-	-	-	17	20.0
0.58	-	-	2	9.5	-	-	-	-	-	-	-	-	-	-	11	12.9

TABLE 46 (Continued)

MONTHLY FREQUENCY OF OCCURRENCE BY NUMBER AND PERCENT OF *HARPACTICUS UNIREMIS* COPEPODITES

Cephalo-thorax length (mm)	Sample Dates															
	7 October 1972				8 November 1972						6 December 1972					
	Copepodites		Adult Females		Copepodite		Adult Males		Adult Females		Copepodites		Adult Males		Adult Females	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
0.60	-	-	2	9.5	-	-	-	-	-	-	-	-	-	-	5	5.8
0.62	-	-	3	14.2	-	-	-	-	-	-	-	-	-	-	-	-
0.64	-	-	1	4.7	-	-	-	-	-	-	-	-	-	-	-	-
0.66	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TOTALS	2	9.5	19	90.4	1	11.1	1	11.1	7	77.7	5	5.8	7	8.2	73	85.8
Mean length Cephalo-thorax	—		0.57		—		—		0.50		—		0.47		0.55	
Standard Deviation	—		0.04		—		—		0.06		—		0.02		0.03	

TABLE 46 (Continued)

MONTHLY FREQUENCY OF OCCURRENCE BY NUMBER AND PERCENT OF *HARPACTICUS UNIREMIS* COPEPODITES

Cephalo-thorax length (mm)	Sample Dates													
	2 January 1973						4 February 1973		5 May 1973					
	Copepodites		Adult Males		Adult Females		Adult Females		Copepodites		Adult Males		Adult Females	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
0.20	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.22	-	-	-	-	-	-	-	-	1	1.4	-	-	-	-
0.24	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.26	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.28	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.30	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.32	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.34	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.36	1	1.4	-	-	-	-	-	-	-	-	-	-	-	-
0.38	-	-	-	-	-	-	-	-	1	1.4	-	-	-	-
0.40	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.42	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.44	-	-	-	-	1	1.4	-	-	-	-	-	-	-	-
0.46	-	-	-	-	1	1.4	-	-	-	-	-	-	-	-
0.48	-	-	1	1.4	3	4.2	1	100	-	-	-	-	2	2.9
0.50	-	-	-	-	9	12.6	-	-	-	-	3	4.4	7	10.2
0.52	-	-	-	-	14	19.7	-	-	-	-	-	-	16	23.5
0.54	-	-	-	-	18	25.3	-	-	-	-	-	-	14	20.5
0.56	-	-	-	-	14	19.7	-	-	-	-	-	-	11	16.1

TABLE 46 (Continued)

MONTHLY FREQUENCY OF OCCURRENCE BY NUMBER AND PERCENT OF *HARPACTICUS UNIREMIS* COPEPODITES

	Sample Dates													
	2 January 1973						4 February 1973		5 May 1973					
Cephalo-thorax length (mm)	Copepodites		Adult Males		Adult Females		Adult Females		Copepodites		Adult Males		Adult Females	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
0.58	-	-	-	-	-	-	6	8.4	-	-	1	1.4	7	10.2
0.60	-	-	-	-	-	-	3	4.2	-	-	-	-	1	1.4
0.62	-	-	-	-	-	-	-	-	-	-	-	-	4	5.8
0.64	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.66	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TOTAL	1	1.4	1	1.4	69	97.1	1	100	2	2.9	4	5.8	62	91.1
Mean length Cephalo-thorax	—		—		0.54		—		—		—		0.54	
Standard Deviation	—		—		0.03		—		—		—		0.03	

TABLE 46 (Continued)

MONTHLY FREQUENCY OF OCCURRENCE BY NUMBER AND PERCENT OF *HARPACTICUS UNIREMIS* COPEPODITES

Cephalothorax length (mm)	Sample Dates																			
	4 June 1973				1 July 1973		31 July 1973				13 Sept. 1973		7 December 1973						7 Jan. 1974	
	Copepodites		Adult Females		Adult Females		Copepodites		Adult Females		Adult Females		Copepodites		Adult Males		Adult Females		Adult Females	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
0.20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.26	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.28	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.30	1	0.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.32	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.34	1	0.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.38	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.40	-	-	-	-	-	-	-	-	-	-	-	-	1	5.9	1	5.9	-	-	-	-
0.42	-	-	-	-	-	-	-	-	-	-	-	-	1	5.9	2	11.7	-	-	-	-
0.44	-	-	3	2.0	-	-	-	-	-	-	-	-	-	-	1	5.9	-	-	-	-
0.46	-	-	4	2.7	-	-	-	-	3	2.6	2	2.5	1	5.9	1	5.9	-	-	-	-
0.48	-	-	6	4.0	2	5.8	-	-	2	1.7	2	2.5	-	-	-	-	-	-	-	-
0.50	-	-	9	6.1	3	8.8	1	0.8	7	6.1	2	2.5	-	-	2	11.7	1	5.9	1	50.0
0.52	-	-	25	17.0	6	17.6	-	-	17	14.9	11	14.1	-	-	-	-	-	-	-	-
0.54	-	-	31	21.0	10	29.4	-	-	22	19.2	23	29.4	-	-	-	-	2	11.7	-	-
0.56	-	-	31	21.0	8	23.5	-	-	33	28.9	15	19.2	-	-	-	-	3	17.6	1	50.0
0.58	-	-	19	12.9	1	2.9	-	-	15	13.1	7	8.9	-	-	-	-	1	5.9	-	-

TABLE 46 (Continued)

MONTHLY FREQUENCY OF OCCURRENCE BY NUMBER AND PERCENT OF *HARPACTICUS UNIREMIS* COPEPODITES

Cephalo-thorax length (mm)	Sample Dates																			
	4 June 1973				1 July 1973		31 July 1973				13 Sept. 1973		7 December 1973						7 Jan. 1974	
	Copepodites		Adult Females		Adult Females		Copepodites		Adult Females		Adult Females		Copepodites		Adult Males		Adult Females		Adult Females	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
0.60	-	-	9	6.1	1	2.9	-	-	6	5.2	9	11.5	-	-	-	-	-	-	-	-
0.62	-	-	7	4.7	3	8.8	-	-	5	4.3	5	6.4	-	-	-	-	-	-	-	-
0.64	-	-	1	0.6	-	-	-	-	2	1.7	2	2.5	-	-	-	-	-	-	-	-
0.66	-	-	-	-	-	-	-	-	1	0.8	-	-	-	-	-	-	-	-	-	-
TOTAL	2	1.3	145	98.6	34	100	1	0.8	113	99.1	78	100	3	17.7	7	41.1	7	41.1	2	100
Mean length Cephalo-thorax	—		0.55		0.54		—		0.59		0.55		—		0.45		0.55		—	
Standard Deviation	—		0.04		0.04		—		0.26		0.04		—		0.04		0.03		—	

TABLE 46 (Continued)

MONTHLY FREQUENCY OF OCCURRENCE BY NUMBER AND PERCENT OF *HARPACTICUS UNIREMIS* COPEPODITES

	Sample Dates															
	27 March 1974						24 April 1974						21, 22 May 1974			
Cephalo-thorax length (mm)	Copepodites		Adult Males		Adult Females		Copepodites		Adult Males		Adult Females		Copepodites		Adult Females	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
0.20	2	0.8	-	-	-	-	1	0.3	-	-	-	-	-	-	-	-
0.22	4	1.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.24	5	2.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.26	7	2.9	-	-	-	-	-	-	-	-	-	-	2	0.9	-	-
0.28	8	3.3	-	-	-	-	-	-	-	-	-	-	1	0.4	-	-
0.30	9	3.7	-	-	-	-	3	1.0	-	-	-	-	-	-	-	-
0.32	3	1.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.34	5	2.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.36	11	4.5	-	-	-	-	-	-	-	-	-	-	2	0.9	-	-
0.38	10	4.1	-	-	1	0.4	4	1.4	-	-	-	-	-	-	-	-
0.40	11	4.5	-	-	-	-	8	2.8	2	0.7	1	0.3	-	-	-	-
0.42	8	3.3	-	-	-	-	11	3.9	1	0.3	1	0.3	-	-	-	-
0.44	8	3.3	-	-	-	-	6	2.1	2	0.7	1	0.3	-	-	-	-
0.46	12	5.0	-	-	1	0.4	-	-	5	1.7	4	1.4	-	-	-	-
0.48	8	3.3	2	0.8	1	0.4	-	-	12	4.2	13	4.6	-	-	6	2.6
0.50	7	2.9	17	7.0	6	2.4	-	-	15	5.3	13	4.6	1	0.4	12	5.3
0.52	-	-	29	12.0	8	3.3	-	-	10	3.5	39	14.0	-	-	26	11.6
0.54	-	-	6	2.4	8	3.3	-	-	5	1.7	52	18.4	-	-	60	26.9
0.56	-	-	6	2.4	15	6.2	-	-	1	0.3	31	11.0	-	-	53	23.7
0.58	-	-	-	-	8	3.3	-	-	-	-	18	6.3	-	-	23	10.3

TABLE 46 (Continued)

MONTHLY FREQUENCY OF OCCURRENCE BY NUMBER AND PERCENT OF *HARPACTICUS UNIREMIS* COPEPODITES

Cephalo-thorax length (mm)	Sample Dates															
	27 March 1974						24 April 1974						21, 22 May 1974			
	Copepodites		Adult Males		Adult Females		Copepodites		Adult Males		Adult Females		Copepodites		Adult Females	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
0.60	-	-	-	-	10	4.1	-	-	-	-	18	6.3	-	-	21	9.4
0.62	-	-	-	-	4	1.6	-	-	-	-	3	1.0	-	-	13	5.8
0.64	-	-	-	-	1	0.4	-	-	-	-	2	0.7	-	-	3	1.3
0.66	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0.4
TOTAL	118	48.9	60	24.9	63	26.1	33	11.7	53	18.8	196	69.5	6	2.7	218	97.3
Mean length Cephalo-thorax	0.37		0.52		0.55		0.40		0.49		0.54		—		0.56	
Standard Deviation	0.08		0.02		0.04		0.04		0.03		0.04		—		0.03	

TABLE 46 (Continued)

MONTHLY FREQUENCY OF OCCURRENCE BY NUMBER AND PERCENT OF *HARPACTICUS UNIREMIS* COPEPODITES

Cephalo-thorax length (mm)	Sample Dates															
	24 June 1974				23 July 1974				19 August 1974				16 Sept. 1974		29 Nov. 1974	
	Copepodites		Adult Females		Copepodites		Adult Females		Copepodites		Adult Females		Adult Females		Adult Females	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
0.20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.26	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.28	-	-	-	-	1	0.4	-	-	-	-	-	-	-	-	-	-
0.30	-	-	-	-	1	0.4	-	-	-	-	-	-	-	-	-	-
0.32	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.34	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.38	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.40	-	-	1	0.7	-	-	-	-	-	-	-	-	-	-	-	-
0.42	-	-	2	1.4	-	-	-	-	-	-	-	-	-	-	-	-
0.44	-	-	7	5.1	-	-	-	-	1	0.9	1	0.9	-	-	-	-
0.46	-	-	4	2.9	1	0.4	3	1.2	-	-	-	-	-	-	-	-
0.48	-	-	12	8.8	-	-	9	3.8	-	-	-	-	-	-	-	-
0.50	1	0.7	17	12.5	-	-	26	10.9	1	0.9	11	10.0	2	1.3	-	-
0.52	-	-	16	11.7	-	-	34	14.3	-	-	23	20.9	11	7.4	-	-
0.54	-	-	29	21.3	1	0.4	54	22.7	1	0.9	34	30.9	25	17.1	-	-
0.56	-	-	20	14.7	-	-	48	20.2	-	-	18	16.3	43	29.4	-	-
0.58	-	-	13	9.5	-	-	30	12.6	-	-	8	7.2	25	17.1	-	-

TABLE 46 (Continued)

MONTHLY FREQUENCY OF OCCURRENCE BY NUMBER AND PERCENT OF *HARPACTICUS UNIREMIS* COPEPODITES

	Sample Dates															
	24 June 1974				23 July 1974				19 August 1974				16 Sept. 1974		29 Nov. 1974	
Cephalo-thorax length (mm)	Copepodites		Adult Females		Copepodites		Adult Females		Copepodites		Adult Females		Adult Females		Adult Females	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
0.60	-	-	10	7.3	-	-	16	6.7	-	-	6	5.5	27	18.4	1	100
0.62	-	-	2	1.4	-	-	7	2.9	-	-	3	2.7	9	6.1	-	-
0.64	-	-	2	1.4	-	-	6	2.5	-	-	3	2.7	4	2.7	-	-
0.66	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TOTAL	1	0.7	135	99.2	4	1.7	233	98.3	3	2.7	107	97.2	146	100	1	100
Mean length Cephalo-thorax	—		0.53		—		0.55		—		0.55		0.57		—	
Standard Deviation	—		0.05		—		0.04		—		0.03		0.03		—	

TABLE 46 (Continued)

MONTHLY FREQUENCY OF OCCURRENCE BY NUMBER AND PERCENT OF *HARPACTICUS UNIREMIS* COPEPODITES

Cephalo-thorax length (mm)	Sample Dates															
	28 December 1974		28 January 1975		24 February 1975						28, 29 March 1975					
	Adult Females		Adult Females		Copepodites		Adult Males		Adult Females		Copepodites		Adult Males		Adult Females	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
0.20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.26	-	-	-	-	-	-	-	-	-	-	2	1.4	-	-	-	-
0.28	-	-	-	-	-	-	-	-	-	-	3	2.2	-	-	-	-
0.30	-	-	-	-	-	-	-	-	-	-	3	2.2	-	-	-	-
0.32	-	-	-	-	-	-	-	-	-	-	2	1.4	-	-	-	-
0.34	-	-	-	-	-	-	-	-	-	-	3	2.2	-	-	-	-
0.36	-	-	-	-	-	-	-	-	-	-	4	2.9	-	-	-	-
0.38	-	-	-	-	-	-	-	-	-	-	4	2.9	-	-	-	-
0.40	-	-	-	-	-	-	-	-	-	-	3	2.2	-	-	-	-
0.42	-	-	-	-	-	-	-	-	-	-	3	2.2	1	0.7	-	-
0.44	-	-	-	-	-	-	-	-	-	-	3	2.2	1	0.7	-	-
0.46	-	-	-	-	-	-	-	-	-	-	3	2.2	2	1.4	2	1.4
0.48	-	-	-	-	-	-	1	5.8	-	-	2	1.4	5	3.6	5	3.6
0.50	-	-	-	-	1	5.8	-	-	1	5.8	-	-	7	5.1	5	3.6
0.52	-	-	-	-	-	-	-	-	2	11.7	-	-	5	3.6	10	7.3
0.54	-	-	-	-	-	-	-	-	2	11.7	-	-	2	1.4	16	11.7
0.56	-	-	1	16.6	-	-	-	-	2	11.7	-	-	-	-	13	9.5
0.58	1	100	2	33.3	-	-	-	-	7	41.1	-	-	-	-	13	9.5

TABLE 46 (Continued)

MONTHLY FREQUENCY OF OCCURRENCE BY NUMBER AND PERCENT OF *HARPACTICUS UNIREMIS* COPEPODITES

	Sample Dates															
	28 December 1974		28 January 1975		24 February 1975						28, 29 March 1975					
Cephalo-thorax length (mm)	Adult Females		Adult Females		Copepodites		Adult Males		Adult Females		Copepodites		Adult Males		Adult Females	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
0.60	-	-	1	16.6	-	-	-	-	1	5.8	-	-	-	-	10	7.3
0.62	-	-	2	33.3	-	-	-	-	-	-	-	-	-	-	4	2.9
0.64	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.66	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TOTAL	1	100	6	100	1	5.8	1	5.8	15	88.2	35	25.7	23	16.9	78	57.3
Mean length Cephalo-thorax	—		—		—		—		0.56		0.37		0.49		0.55	
Standard Deviation	—		—		—		—		0.03		0.07		0.03		0.04	

TABLE 46 (Continued)

MONTHLY FREQUENCY OF OCCURRENCE BY NUMBER AND PERCENT OF *HARPACTICUS UNIREMIS* COPEPODITES

Cephalo-thorax length (mm)	Sample Dates											
	28 April 1975						30 May 1975					
	Copepodites		Adult Males		Adult Females		Copepodites		Adult Males		Adult Females	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
0.20	-	-	-	-	-	-	-	-	-	-	-	-
0.22	-	-	-	-	-	-	-	-	-	-	-	-
0.24	-	-	-	-	-	-	-	-	-	-	-	-
0.26	-	-	-	-	-	-	-	-	-	-	-	-
0.28	-	-	-	-	-	-	-	-	-	-	-	-
0.30	1	0.4	-	-	-	-	-	-	-	-	-	-
0.32	2	0.9	-	-	-	-	-	-	-	-	-	-
0.34	2	0.9	-	-	-	-	-	-	-	-	-	-
0.36	5	2.2	-	-	-	-	-	-	-	-	-	-
0.38	7	3.1	-	-	-	-	-	-	-	-	-	-
0.40	9	4.0	1	0.4	-	-	1	0.2	-	-	-	-
0.42	9	4.0	2	0.9	-	-	1	0.2	1	0.2	-	-
0.44	6	2.6	2	0.9	-	-	2	0.5	1	0.2	-	-
0.46	2	0.9	6	2.6	2	0.9	3	0.8	3	0.8	-	-
0.48	-	-	16	7.1	7	3.1	4	1.1	6	1.7	8	2.3
0.50	-	-	19	8.4	7	3.1	3	0.8	8	2.3	17	4.8
0.52	-	-	13	5.7	22	9.7	-	-	5	1.4	37	10.5
0.54	-	-	6	2.6	33	14.6	-	-	3	0.8	86	24.5
0.56	-	-	-	-	19	8.4	-	-	1	0.2	75	21.4
0.58	-	-	-	-	14	6.2	-	-	-	-	32	9.1

TABLE 46 (Continued)

MONTHLY FREQUENCY OF OCCURRENCE BY NUMBER AND PERCENT OF *HARPACTICUS UNIREMIS* COPEPODITES

	Sample Dates											
	28 April 1975						30 May 1975					
Cephalo-thorax length (mm)	Copepodites No.	Copepodites %	Adult Males No.	Adult Males %	Adult Females No.	Adult Females %	Copepodites No.	Copepodites %	Adult Males No.	Adult Males %	Adult Females No.	Adult Females %
0.60	-	-	-	-	11	4.8	-	-	-	-	30	8.5
0.62	-	-	-	-	1	0.4	-	-	-	-	18	5.1
0.64	-	-	-	-	1	0.4	-	-	-	-	4	1.1
0.66	-	-	-	-	-	-	-	-	-	-	1	0.2
TOTAL	43	19.1	65	28.9	117	52.0	14	4.0	28	8.0	308	88.0
Mean length Cephalo-thorax	0.40		0.49		0.54		0.46		0.50		0.56	
Standard Deviation	0.04		0.03		0.03		0.03		0.03		0.03	

TABLE 47

SIZE FREQUENCY DISTRIBUTION OF *HARPACTICUS UNIREMIS* COPEPODITES ON DAYVILLE FLATS FROM 15 MAY 1972 AND 27 MARCH 1974

Cephalo-thorax length (mm)	Sample Dates											
	15 May 1972						27 March 1974					
	Copepodite Males		Copepodite Females		Copepodite-sex not determined		Copepodite Males		Copepodite Females		Copepodite-sex not determined	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
0.20	-	-	-	-	3	1.2	-	-	-	-	2	1.6
0.22	-	-	-	-	4	1.6	-	-	-	-	4	3.3
0.24	-	-	-	-	10	4.1	-	-	-	-	5	4.2
0.26	-	-	-	-	23	9.5	-	-	-	-	7	5.9
0.28	-	-	-	-	22	9.0	-	-	-	-	8	6.7
0.30	-	-	-	-	22	9.0	-	-	-	-	9	7.5
0.32	1	0.4	-	-	7	2.8	-	-	-	-	3	2.5
0.34	-	-	-	-	11	4.5	-	-	-	-	5	4.2
0.36	3	1.2	6	2.4	7	2.8	2	1.6	4	3.3	5	4.2
0.38	1	0.4	7	2.8	2	0.8	2	1.6	4	3.3	4	3.3
0.40	9	3.7	10	4.1	5	2.0	3	2.5	4	3.3	4	3.3
0.42	8	3.3	7	2.8	-	-	4	3.3	4	3.3	-	-
0.44	6	2.4	8	3.3	-	-	3	2.5	5	4.2	-	-
0.46	2	0.8	25	10.3	-	-	1	0.8	11	9.3	-	-
0.48	-	-	19	7.8	-	-	-	-	8	6.7	-	-
0.50	-	-	12	4.9	-	-	-	-	7	5.9	-	-
0.52	-	-	1	0.4	-	-	-	-	-	-	-	-

TABLE 47 (Continued)

SIZE FREQUENCY DISTRIBUTION OF *HARPACTICUS UNIREMIS* COPEPODITES ON DAYVILLE FLATS

	Sample Dates											
	15 May 1972						27 March 1974					
Cephalo-thorax length (mm)	Copepodite Male No.	Copepodite Male %	Copepodite Females No.	Copepodite Females %	Copepodite-sex not determined No.	Copepodite-sex not determined %	Copepodite Males No.	Copepodite Males %	Copepodite Females No.	Copepodite Females %	Copepodite-sex not determined No.	Copepodite-sex not determined %
0.54	-	-	-	-	-	-	-	-	-	-	-	-
0.56	-	-	-	-	-	-	-	-	-	-	-	-
0.58	-	-	1	0.4	-	-	-	-	-	-	-	-
TOTALS	30	12.4	96	39.6	116	47.9	15	12.7	47	39.8	56	47.4
Mean length Cephalo-thorax	0.41		0.45		0.29		0.41		0.44		0.30	
Standard Deviation	0.03		0.04		0.05		0.03		0.04		0.06	

	15 May 1972 and 27 March 1974					
	Copepodite Males No.	Copepodite Males %	Copepodite Females No.	Copepodite Females %	Copepodite-sex not determined No.	Copepodite-sex not determined %
TOTALS	45	12.5	143	39.7	172	47.7
Mean length Cephalothorax	0.41		0.45		0.29	
Standard Deviation	0.03		0.04		0.05	

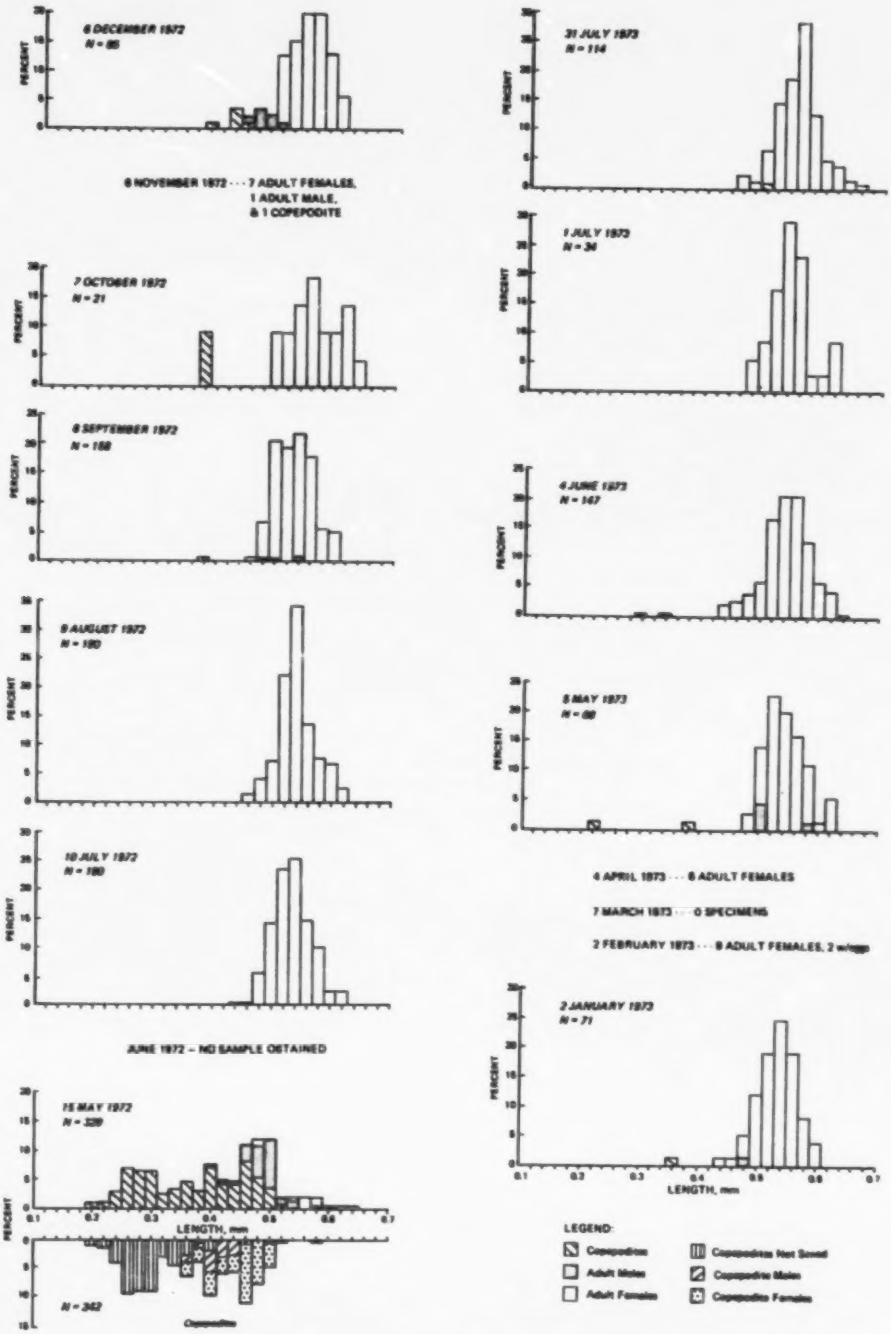

Figure 14. The percent length-frequency distribution of *Harpacticus uniremis* collected on Dayville Flats from May 1972 through May 1975. Lengths plotted are cephalothorax measurements (continued on next page).

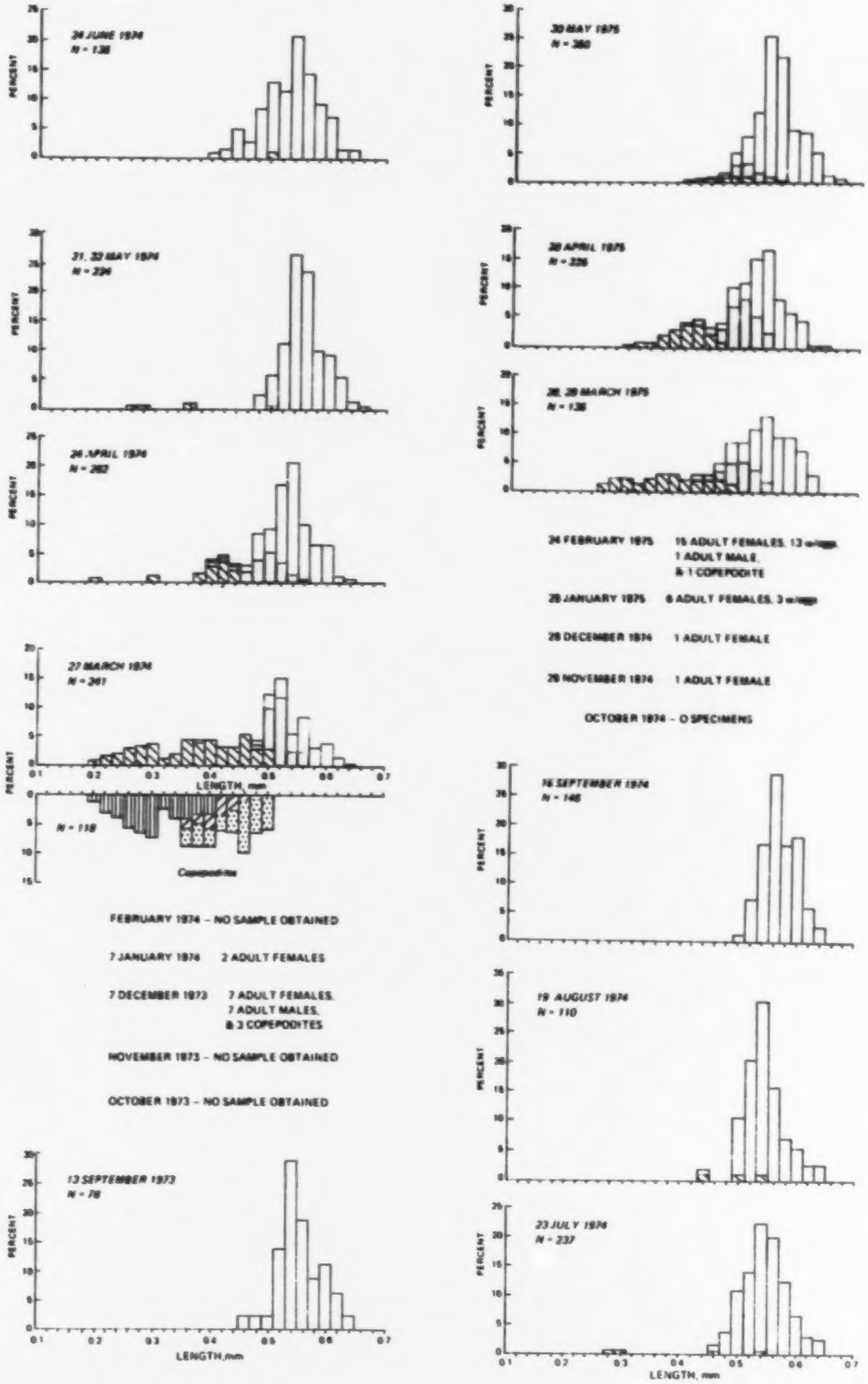

Figure 14 (Continued). See Figure 14, previous page.

Egg-bearing females occurred from December through May with most individuals occurring in February and March. Copepodites were most abundant in March, April and May (Table 48). We conclude that the time interval from virtually the last appearance of egg sacs to the virtual disappearance of copepodites is that needed for growth to adult, i.e., from March to May, or two to three months. Supporting this supposition is the data from two full years of sampling (1974 and 1975) in which the time interval between the major appearance of female copepodites (March) and the appearance of the largest modal-length group of females (0.54 mm) in May is also two to three months. The period between the major appearance of male copepodites (March) and the appearance of the largest modal-length group of adult males (0.50 mm, April) suggests that they develop to adults in one to one and one-half months.

SEX RATIO

In a number of harpacticoid species, males reach maturity before females, and grasp only copepodid females (Itô, 1971[61]; Barnett, 1970[65]; Lasker *et al.*, 1970[66]). This situation is also true for *Harpacticus uniremis*. Female copepodites (39.7% of the copepodid population) in the collections of 15 May 1972 and 27 March 1974 outnumbered male copepodites (12.5% of the copepodid population) three to one. On these two dates there were nearly twice as many adult males as copepodid males; conversely, female copepodites were more abundant than adult females (Table 47; Figure 14). These data demonstrate that males of the year reach maturity first and mate with copepodid females of their own generation.

Copepodites with sex not determined (Stages I-III) from the samples of May 1972 and March 1974 accounted for 47.7% of the copepodid population.

REPRODUCTION

Approximately three years of sampling is represented in Figure 15 and Table 48 which show the numbers and percentages of copepodites, adult males and females, females with eggs and clasping individuals collected during this period.

TABLE 48

SEASONAL CHANGES IN THE MONTHLY COMPOSITION OF *HARPACTICUS UNIREMIS* ON DAYVILLE FLATS FROM MAY 1972 THROUGH MAY 1975

Date	Number of[a] samples examined	Females		Males		Copepodites		TOTAL MEASURED	SAMPLE TOTAL	Females w/eggs of Total Female Population		Clasping In-dividuals of Total Population[b]	
		Number	%	Number	%	Number	%			Number	%	Number	%
15 May '72	Qual. Sample	70(18)[c]	5.3[25][d]	275(69)	20.9[25]	970[242]	73.8[25]	329	1315	5	7.1	18	1.3
June '72	NO SAMPLE OBTAINED												
10 July '72	2(C)[e]	190(190)	100[100]	0	0	0	0	190	190	0	0	0	0
9 Aug. '72	4(C)	380(190)	100[50]	0	0	0	0	190	380	0	0	0	0
8 Sept.'72	5(C)	309(154)	98.7[50]	2(2)	0.6[100]	2(2)	0.6[100]	158	313	0	0	2	0.6
7 Oct. '72	6(C)	20(20)	95.2[100]	0	0	1(1)	4.8[100]	21	21	0	0	0	0
6 Nov. '72	5(C)	7(7)	77.8[100]	1(1)	11.1[100]	1(1)	11.1[100]	9	9	0	0	0	0
6 Dec. '72	7(C)	72(72)	84.7[100]	7(7)	8.2[100]	5(5)	5.8[100]	85	85	1(1)	1.4[100]	6(6)	7.0[100]
2 Jan. '73	12(C)	69(69)	97.1[100]	1(1)	1.4[100]	1(1)	1.4[100]	71	71	6(6)	8.7[100]	0	0
4 Feb. '73	5(C)	9(1)	100[11.1]	0	0	0	0	9	9	2	22.2	0	0
7 Mar. '73	6(C)	0	0	0	0	0	0	0	0	0	0	0	0
4 Apr. '73	4(C)	6	100	0	0	0	0	0	6	0	0	0	0
5 May '73	5(C)	62(62)	87.3[100]	5(4)	7.0[80]	4(2)	5.6[50]	68	71	0	0	2(2)	2.8[100]
4 June '73	6(C)	145(145)	98.6[100]	0	0	2(2)	1.3[100]	147	147	0	0	0	0
1 July '73	2(C)	34(34)	100[100]	0	0	0	0	34	34	0	0	0	0
31 July '73	5(C)	114(114)	100[100]	0	0	0	0	114	114	0	0	0	0

TABLE 48 (Continued)

SEASONAL CHANGES IN THE MONTHLY COMPOSITION OF *HARPACTICUS UNIREMIS*

Date	Number of[a] samples examined	Females		Males		Copepodites		TOTAL MEASURED	SAMPLE TOTAL	Females w/eggs of Total Female Population		Clasping Individuals of Total Population[b]	
		Number	%	Number	%	Number	%			Number	%	Number	%
13 Sept. '73	5(C)	78(78)	100[100]	0	0	0	0	78	78	C	0	0	0
Oct. '73	NO SAMPLE OBTAINED												
Nov. '73	NO SAMPLE OBTAINED												
7 Dec. '73	5(C)	7(7)	41.1[100]	7(7)	41.1[100]	3(3)	17.6[100]	17	17	0	0	0	0
7 Jan. '74	4(C)	2(2)	100[100]	0	0	0	0	2	2	0	0	0	0
Feb. '74	NO SAMPLE OBTAINED												
27 Mar. '74	7(P)[f]	252(63)	26.2[25]	236(60)	24.6[25]	472(118)	49.1[25]	241	960	121(30)	48.0[25]	50	5.1
24 Apr. '74	2(P)	392(196)	69.6[50]	106(53)	18.8[50]	65(33)	11.5[50]	282	563	5(5)	1.3[100]	42(4)	7.4[9.5]
21,22 May'74	2(P)	875(218)	99.3[25]	1(1)	0.1[100]	5(5)	0.5[100]	224	881	0	0	0	0
24 June '74	2(P)	135(135)	98.5[100]	0	0	1(1)	0.7[100]	136	136	0	0	0	0
23 July '74	6(C)	233(233)	97.9[100]	0	0	5(4)	2.1[80]	237	238	0	0	0	0
19 Aug. '74	2(P)	107(107)	97.2[100]	0	0	3(3)	2.7[100]	110	110	0	0	0	0
16 Sept. '74	6(P)	146(146)	100[100]	0	0	0	0	146	146	0	0	0	0
31 Oct. '74	3(P)	0	0	0	0	0	0	0	0	0	0	0	0
29 Nov. '74	3(P)	1(1)	100[100]	0	0	0	0	1	1	0	0	0	0
28 Dec. '74	3(P)	1(1)	100[100]	0	0	0	0	1	1	0	0	0	0

TABLE 48 (Continued)

SEASONAL CHANGES IN THE MONTHLY COMPOSITION OF *HARPACTICUS UNIREMIS*

Date	Number of[a] samples examined	Females		Males		Copepodites		TOTAL MEASURED	SAMPLE TOTAL	Females w/eggs of Total Female Population		Clasping In-[b] dividuals of Total Population	
		Number	%	Number	%	Number	%			Number	%	Number	%
28 Jan. '75	3(P)	6(6)	100[100]	0	0	0	0	6	6	3(3)	50.0[100]	0	0
24 Feb. '75	3(P)	15(15)	88.2[100]	1(1)	5.8[100]	1(1)	5.8[100]	17	17	13[13]	86.6[100]	0	0
28,29 Mar.'75	6(P)	78(78)	57.3[100]	23(23)	16.9[100]	35(35)	25.7[100]	136	136	61(61)	78.2[100]	4(4)	2.9[100]
28 Apr. '75	3(P)	468(117)	52.0[25]	258(65)	28.7[25]	173(43)	19.2[25]	225	899	14(14)	2.9[100]	86	9.5
30 May '75	3(P)	1235(308)	96.7[25]	28(28)	2.1[100]	14(14)	1.0[100]	350	1277	0	0	0	0

[a] Core (C) = 10 cm^2; Plot (P) = 100 cm^2

[b] Individuals in clasping pairs included in the male and copepodite totals

[c] Values within ( ), refer to number of individuals measured

[d] Values within [ ], refer to the percent of individuals measured

[e] Density data used for July 1972 through January 1974 and July 1974 are taken from available archived cores

[f] Density data used for March 1974 through May 1975 were derived from 100 cm^2 plots specifically selected to increase the number of copepods available

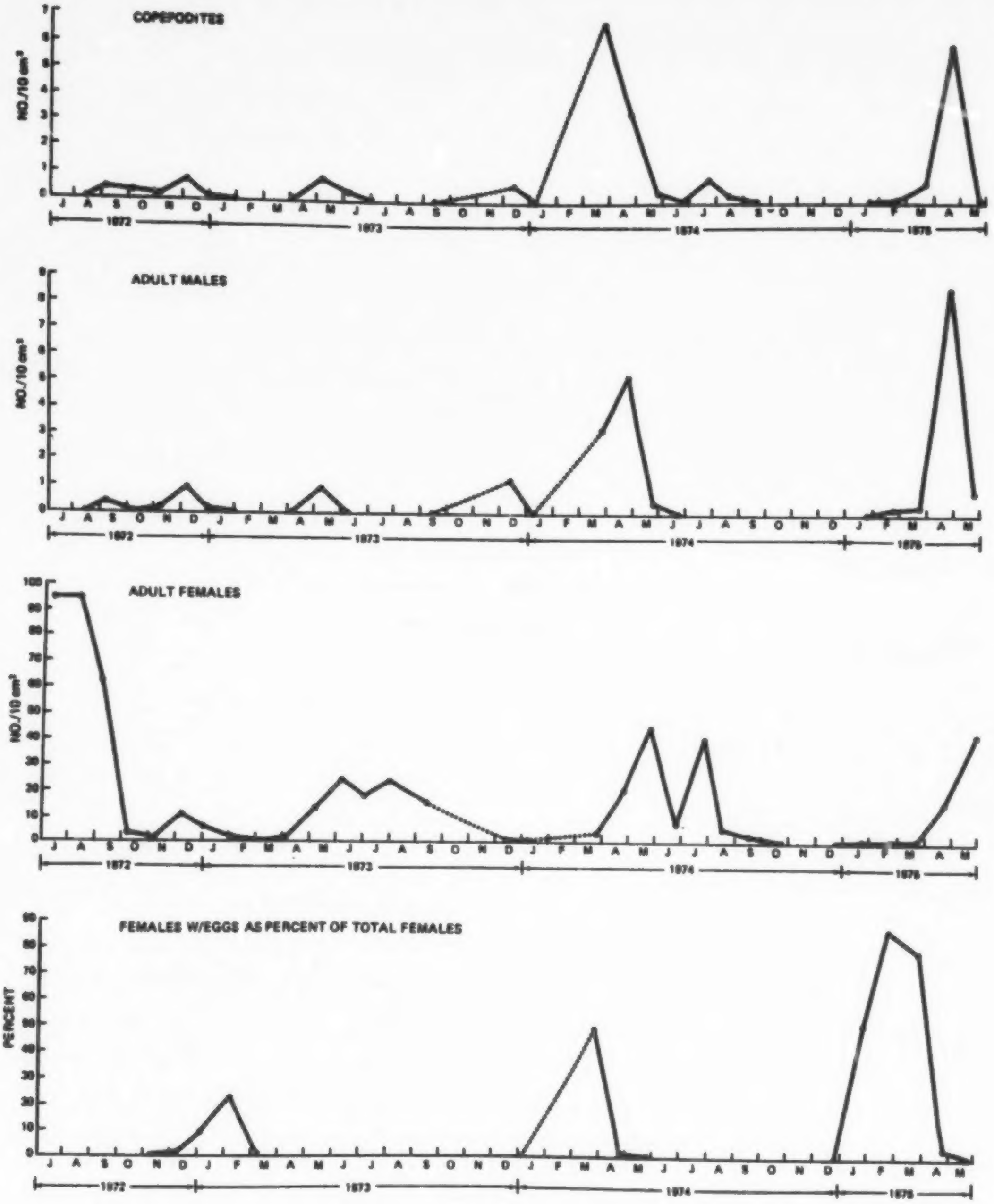

Figure 15. Seasonal variation in numbers of *Harpacticus uniremis* copepodites, adult males and adult females and the percentage of ovigerous females from the total number of adult females. Dotted lines indicate months where no sample was obtained, and is an approximation only. See Figure 16 for total copepod densities for all months.

Adult males were found clasping Stage IV and V female copepodites but never adult females. Juvenile males were never observed in a mating pair. The most frequent combination was an adult male and a Stage V copepodid female. Willey (1931)[67] discussed the phenomenon of precocious mating and concludes that it is probably a common occurrence. However, mating pairs between adults have been observed in other harpacticoid species (Fraser, 1936[68]; Barnett, 1966[69]). Lasker *et al.* (1970)[66] suggested that spermatophore transfer does not take place until the female is mature. Fraser (1936)[68] and Barnett (1966)[69] also observed precocious mating, but did not comment on spermatophore transfer. We observed spermatophores attached only to adult females (observations of July 1974 and March 1975). It seems unlikely that spermatophore transfer takes place during precocious coupling, as the spermatophore would be lost at the molt to maturity. Therefore, it is assumed that the adult male grasps the Stage V copepodid female until she molts to maturity, after which time the spermatophore is transferred to the seminal receptacle of the female (see also Meglitsch, 1972[70] for discussion of reproductive behavior in copepods). Other authors have noted adult males grasping copepodites smaller than Stage V (Barnett, 1966[69]; Lasker *et al.*, 1970[66]), but the advantage to this early coupling is not known.

Harpacticus uniremis has a relatively distinct reproductive period during which time copepodites, adult males and females, and ovigerous females are found in the population. Mating pairs occurred from September through May with maximum numbers of clasping individuals appearing in April (Table 48). Generally, mating pairs were not abundant, but, it is probable, that additional pairs were present, and were separated during the extraction process. The presence of copepodites and adult males in the same months that mating pairs were observed (Table 48; Figure 15) further emphasizes this period as an important one for reproductive activity in this species. During April, while clasping was still taking place, the number of ovigerous females tended to be greatly reduced with all egg-bearers gone from the population by May or June. Thus, it is apparent that spermatophore transfer during this period does not result in immediate fertilization and egg production. Instead, adult females bearing egg sacs begin to appear around December or January. Therefore, it appears that egg production occurs approximately nine to ten months after copulation, as exemplified by the time between maximum density peaks of copulating pairs (males and copepodites) and ovigerous females (i.e., a period of approximately nine months from the peak of clasping in May 1972 through the peak of ovigerous females in February 1973; ten months from the clasping peak in May 1973 through the ovigerous female peak in March 1974; ten months from the April 1974 clasping peak through the peak of ovigerous females in February 1975). It is, thus, apparent that adult females live for at least ten months and probably longer. Males are present in the population for not longer than six months per year (Figures 14 and 15; Tables 46 and 48).

An increase in copepod activity was apparent in late fall and early winter of 1972 and 1973, a period when meiofauna generally become less abundant (see discussion on meiofaunal density fluctuation in Section VI). This increase in activity was also reflected by an increment of meiofauna at Dayville Flats and Mineral Creek at this time, and has been related to a water temperature increment (Section VI). The winter surge of meiofauna on both of these beaches indicates that temporary increases in these organisms can occur at the coldest period of the year when primary productivity is lowest.

Harpacticus uniremis evidently produces a single brood each year. In late winter and early spring, ovigerous females, copepodites, adult males and females, and copulating pairs are present in the population. By June only non-gravid females are typically present, and they are the only ones typically found for the balance of the year until ovigerous females appear once again in December (Figures 14 and 15; Table 48). Females carrying eggs are then found from December through May.

In February and March of 1975, the percent of females with eggs from the total female population was 86.6 and 78.2 respectively. These were the highest values for ovigerous females noted during the entire study period (Table 48). The fecundity of *Harpacticus uniremis* is greater than that reported for other harpacticoid copepods. (Harris, 1972[71], 1973[72]; Lasker *et al.*, 1970[66]; McIntyre, 1969[36].) The harsh environmental conditions typical of sediment beaches in Port Valdez and the resultant selective pressures acting on *H. uniremis* there apparently have resulted in a higher fecundity for this copepod species than that found for harpacticoids elsewhere (Barnett, 1968[35]; Lasker *et al.*, 1970[66]). The mean number of eggs counted in 85 *H. uniremis* egg sacs was 119 ± 36.3 with the mean length of these egg sacs 0.63 ± 0.08 mm. Itô (1971)[61] examined ten egg sacs of *H. uniremis* from the northern Japanese province of Hokkaido, and found the mean number of eggs to be as much as 229 ± 35.4.

A transect made on 10 July 1972 demonstrated that adult females were widely dispersed intertidally on Dayville Flats at this time. Another transect made on 29 March 1975 also demonstrated no difference ($\alpha = 0.05$) between mean numbers of *Harpacticus uniremis* at each of eight tide levels (Newman-Keuls multiple comparison test with equal sample size; Table 49) (Zar, 1974[64]). The number of ovigerous females taken from all of the stations along the transect of 29 March 1975 were then compared using the Newman-Keuls multiple comparison test with equal sample sizes (three 100 cm^2 plots) (Table 49). In this test, the mean number of ovigerous females at 0.0 m did not equal or was greater than the mean number of ovigerous females at the other tidal levels of -4.0 m, -2.4 m, -1.0 m, -0.5 m, 0.5 m, 1.5 m and 3.0 m ($\alpha = 0.05$; Table 49); approximately 70% of the egg-bearing individuals occurred at 0.0 m on this transect. The baseline collection (at 0.0 m) made 28 and 29 March 1975 (Table 48) indicated that 78% of the total females collected at this station were ovigerous. These data indicate that ovigerous females mainly occupy the mid-tide level.

POPULATION DENSITY RELATIONSHIPS

Densities of harpacticoid copepods have been reported by others as numbers per 10 cm^2 (Harris, 1972[71], 1972[73], 1972[74]; McIntyre, 1969[36]; Wigley and McIntyre, 1964[75]) and number per m^2 (Barnett, 1968[35]; Muus, 1967[41]; Perkins 1974[76]). All sample densities in this chapter are similarly presented (i.e., counts per 10 cm^2 and m^2) for comparative purposes. Densities are examined in conjunction with changes in water temperature, sediment surface temperature and salinity (Figure 16; Table 50).

A pattern of high densities of *Harpacticus uniremis* during spring and summer months and low numbers during fall and winter months generally persisted

TABLE 49

NEWMAN-KEULS MULTIPLE COMPARISON TEST WITH EQUAL SAMPLE SIZES. DATA ARE OVIGEROUS FEMALES COLLECTED FROM THREE 100 cm^2 PLOTS TAKEN AT EACH OF EIGHT DIFFERENT TIDAL LEVELS AT DAYVILLE FLATS, PORT VALDEZ ON 29 MARCH 1975. MEAN NUMBER OF OVIGEROUS FEMALES AT EACH TIDAL HEIGHT IS RANKED IN ASCENDING ORDER:

(-4.0m)	(-1.0m)	(-0.5m)	(-2.4m)	(1.5m)	(3.0m)	(0.5m)	(0.0m)
$\bar{x}_1$-0.00	$\bar{x}_2$=0.00	$\bar{x}_3$=0.33	$\bar{x}_4$=0.67	$\bar{x}_5$=1.00	$\bar{x}_6$=1.67	$\bar{x}_7$=3.67	$\bar{x}_8$=15.00

Comparison (B vs. A)	Difference ($\bar{x}_B - \bar{x}_A$)	SE[a]	q[b]	p[c]	q (0.05, 16, P)[d]	Conclusion[e]
8 vs. 1	15.00	2.79	5.37	8	4.897	Reject H_o: $\mu_8 = \mu_1$
8 vs. 2	15.00	2.79	5.37	7	4.741	Reject H_o: $\mu_8 = \mu_2$
8 vs. 3	14.67	2.79	5.25	6	4.557	Reject H_o: $\mu_8 = \mu_3$
8 vs. 4	14.33	2.79	5.13	5	4.333	Reject H_o: $\mu_8 = \mu_4$
8 vs. 5	14.00	2.79	5.01	4	4.046	Reject H_o: $\mu_8 = \mu_5$
8 vs. 6	13.33	2.79	4.77	3	3.649	Reject H_o: $\mu_8 = \mu_6$
8 vs. 7	11.33	2.79	4.06	2	2.998	Reject H_o: $\mu_8 = \mu_7$
7 vs. 1	3.67	2.79	1.31	7	4.741	Accept H_o: $\mu_7 = \mu_1$
7 vs. 2	3.67	2.79	1.31	6	4.557	Accept H_o: $\mu_7 = \mu_2$
7 vs. 3	3.34	2.79	1.07	5	4.333	Accept H_o: $\mu_7 = \mu_3$
7 vs. 4	3.00	2.79	1.07	4	4.046	Accept H_o: $\mu_7 = \mu_4$
7 vs. 5	2.67	2.79	0.95	3	3.649	Accept H_o: $\mu_7 = \mu_5$
7 vs. 6	2.00	2.79	0.71	2	2.998	Accept H_o: $\mu_7 = \mu_6$
6 vs. 1	1.67	2.79	0.59	6	4.557	Accept H_o: $\mu_6 = \mu_1$
6 vs. 2	1.67	2.79	0.59	5	4.333	Accept H_o: $\mu_6 = \mu_2$
6 vs. 3	1.34	2.79	0.48	4	4.046	Accept H_o: $\mu_6 = \mu_3$

TABLE 49 (Continued)

NEWMAN-KEULS MULTIPLE COMPARISON TEST WITH EQUAL SAMPLE SIZES.

Comparison (B vs. A)	Difference $(\bar{x}_B - \bar{x}_A)$	SE[a]	q[b]	p[c]	q (0.05, 16, P)[d]	Conclusion[e]
6 vs. 4	1.00	2.79	0.35	3	3.649	Accept H_o: $\mu_6 = \mu_4$
6 vs. 5	0.67	2.79	0.24	2	2.998	Accept H_o: $\mu_6 = \mu_5$
5 vs. 1	1.00	2.79	0.35	5	4.333	Accept H_o: $\mu_5 = \mu_1$
5 vs. 2	1.00	2.79	0.35	4	4.046	Accept H_o: $\mu_5 = \mu_2$
5 vs. 3	0.67	2.79	0.24	3	3.649	Accept H_o: $\mu_5 = \mu_3$
5 vs. 4	0.33	2.79	0.11	2	2.998	Accept H_o: $\mu_5 = \mu_4$
4 vs. 1	0.67	2.79	0.24	4	4.046	Accept H_o: $\mu_4 = \mu_1$
4 vs. 2	0.67	2.79	0.24	3	3.649	Accept H_o: $\mu_4 = \mu_2$
4 vs. 3	0.34	2.79	0.12	2	2.998	Accept H_o: $\mu_4 = \mu_3$
3 vs. 1	0.33	2.79	0.11	3	3.649	Accept H_o: $\mu_3 = \mu_1$
3 vs. 2	0.33	2.79	0.11	2	2.998	Accept H_o: $\mu_3 = \mu_2$
2 vs. 1	0.0	2.79	0	2	2.998	Accept H_o: $\mu_2 = \mu_1$

[a] $SE = \sqrt{\frac{s^2}{n}}$ where SE = standard error; s^2 = the error mean square from the analysis of variance; n = the number of data in each of groups A and B.

[b] $q = \frac{\bar{x}_B - \bar{x}_A}{SE}$

[c] p = Number of means in the range of means being tested.

[d] $q\alpha, v, p$ is obtained from Table D.12 (Zar, 1974): v = the error degrees of freedom.

[e] If calculated q is equal to or greater than the critical value, $q\alpha, v, p$, then $H_o = \mu_A$ is rejected.

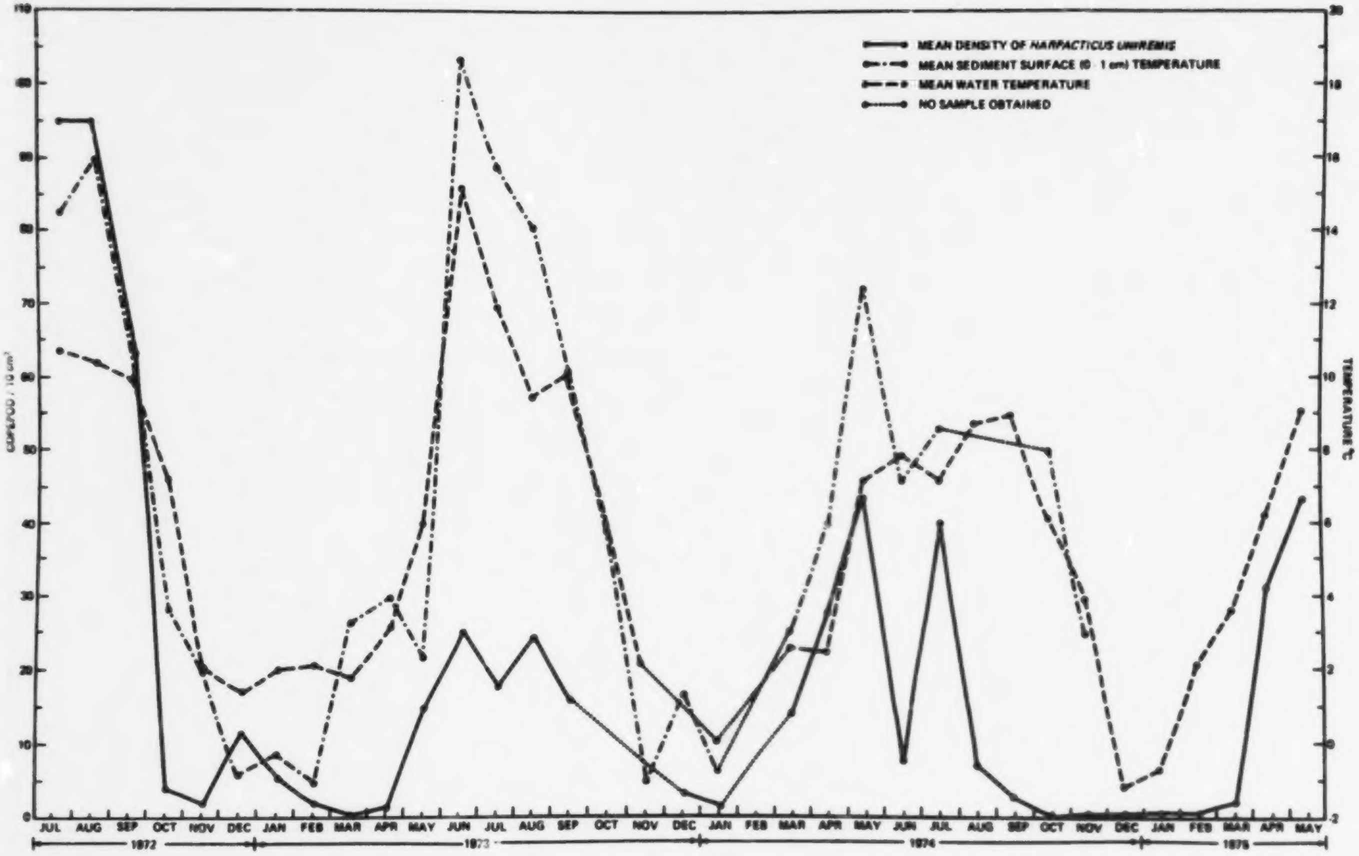

Figure 16. Seasonal population density-temperature relationships of *Harpacticus uniremis* on Dayville Flats, Port Valdez, Alaska.

TABLE 50

DENSITIES OF *HARPACTICUS UNIREMIS* ON DAYVILLE FLATS AS RELATED TO MEAN WATER TEMPERATURE, SEDIMENT SURFACE TEMPERATURE, WATER SALINITY AND SEDIMENT SURFACE SALINITY

Date	Area Sampled[a] (cm^2)	Mean No. 10 cm^2	Mean No. M^2	Mean H_2O Temp.	Mean Sediment Surface Temp.	Surface H_2O Sal.	Sediment Surface Sal.
July 72	20(C)	95	95,000	10.7	14.5	NSO	NSO
Aug. 72	40(C)	95	95,000	10.4	16.0	NSO	NSO
Sept. 72	50(C)	63	63,000	9.8	10.1	NSO	NSO
Oct. 72	60(C)	4	4,000	7.1	3.6	NSO	NSO
Nov. 72	50(C)	2	2,000	1.9	1.8	NSO	NSO
Dec. 72	70(C)	12	12,000	1.3	-0.85	NSO	NSO
Jan. 73	120(C)	6	6,000	2.0	-0.25	NSO	29.5
Feb. 73	50(C)	2	2,000	2.1	-1.1	NSO	NSO
Mar. 73	60(C)	0	0	1.8	3.3	12.8	NSO
Apr. 73	40(C)	2	2,000	3.2	4.0	1.6	27.3
May 73	50(C)	14	14,000	6.0	2.2	13.0	27.9
June 73	60(C)	24	24,000	15.5	19.0	NSO	29.2
July 73	20(C)	17	17,000	12.0	16.1	20.7	24.1
Aug. 73	50(C)	23	23,000	9.6	14.4	2.1	19.0
Sept. 73	50(C)	16	16,000	10.2	10.5	18.6	NSO
Oct. 73	NSO[b]	--	--	5.8	6.0	NSO	NSO
Nov. 73	NSO	--	--	2.3	-1.0	NSO	NSO
Dec. 73	50(C)	3	3,000	--	1.4	NSO	NSO

TABLE 50 (Continued)

Date	Area Sampled[a] (cm^2)	Mean No. 10 cm^2	Mean No. M^2	Mean H_2O Temp.	Mean Sediment Surface Temp.	Surface H_2O Sal.	Sediment Surface Sal.
Jan. 74	40(C)	1	1,000	0	-0.8	30.5	NSO
Feb. 74	NSO[b]	--	--	--	--	NSO	NSO
Mar. 74	700(P)	14	14,000	2.6	3.1	30.0	36.2
Apr. 74	200(P)	28	28,000	2.5	6.0	20.0	32.8
May 74	200(P)	44	44,000	7.3	12.6	12.0	34.0
June 74	200(P)	7	7,000	7.9	7.4	1.7	16.0
July 74	60(C)	40	40,000	7.1	8.6	4.6	NSO
Aug. 74	200(P)	6	6,000	8.8	--	6.9	NSO
Sept.74	600(P)	2	2,000	9.0	--	13.8	18.0
Oct. 74	300(P)	0	0	6.0	8.0	2.0	18.0
Nov. 74	300(P)	<1	30	2.8	2.9	26.7	NSO
Dec. 74	300(P)	<1	30	-1.4	--	30.5	NSO
Jan. 75	300(P)	<1	200	-1.0	--	NSO	NSO
Feb. 75	300(P)	<1	600	2.0	--	NSO	NSO
Mar. 75	600(P)	2	2,000	3.5	--	33.0	NSO
Apr. 75	300(P)	30	30,000	6.6	--	21.0	NSO
May 75	300(P)	43	43,000	9.0	--	13.3	NSO

[a] Core (C) = 10 cm^2; Plot (P) = 100 cm^2

[b] NSO = No sample obtained

throughout this study. *Harpacticus uniremis* was typically most abundant from April to October with the highest numbers recorded in July and August 1972 (95 per 10 cm^2 in both months) (Figure 16; Table 50). By October 1972 the total number of copepods had dropped to 4 per 10 cm^2 and remained low, with a slight increase in December 1972 (12 per 10 cm^2), until May 1973 when numbers began to rise again. No samples were obtained during October and November 1973 and February 1974 due to adverse weather conditions. Based on the scarcity of *H. uniremis* during the latter months in other years and the low densities in December 1973 and January 1974, it is assumed the numbers were also low in the months not sampled. *Harpacticus uniremis* was not found in March 1973 and October 1974. A decline in density occurred in June and August 1974 (7 per 10 cm^2 and 6 per 10 cm^2 respectively), two months when densities are normally highest. Densities were lowest between October 1974 and February 1975. During the latter months, when 300 cm^2 was examined each month, densities ranged from 0 per 10 cm^2 in October 1974 to less than 1 per 10 cm^2 in February 1975.

Seasonal fluctuations of harpacticoid copepods are probably the result of the interaction of various ecological factors, e.g., temperature, salinity, and primary productivity. Muus (1967)[41] emphasized that water temperature is important in controlling reproduction in harpacticoid copepods. Marshall and Orr (1955)[77] considered that the temperature of seawater plays an important part in determining the number of generations of the calanoid copepod, *Calanus*. Harris (1972)[71] suggested that water temperature change is the most important environmental factor affecting copepod reproduction. Densities of harpacticoids have been observed to be directly proportional to water temperature (de Bovée and Soyer, 1974[55]; Harris, 1972[71]; Muus, 1967[41]; Perkins, 1974[76]; Schmidt, 1968[78]; and Straarup, 1970[47]). However, Itô (1971)[61] in a study on *Harpacticus uniremis* in Hokkaido, Japan, reported that the population of the copepod gradually began to increase while temperatures were still dropping but then the population dropped markedly at the highest temperature recorded (10°C). In marked contrast, the months of highest densities of *H. uniremis* at Dayville Flats were typically those months with highest water temperatures and highest sediment surface temperatures (Figure 16). Typically, sediment surface temperatures at low tide were higher than water temperatures during the summer and lower than water temperatures during the winter. Mean sediment surface temperatures for the months of high *H. uniremis* densities were as follows: July through September 1972: 13.5 ± 3.07°C; May through October 1973: 11.4 ± 6.38°C; and April through July 1974: 8.7 ± 2.84°C. An exception to densities being directly proportional to temperature was observed in December 1972 and January 1973. In December 1972, a month when densities are normally at a minimum, the count rose to 12 per 10 cm^2 while water temperature and sediment surface temperature were 1.3°C and -0.85°C respectively. Conversely, densities of *H. uniremis* declined in August, September and October 1974, months when temperatures were still high.

The density of *Harpacticus uniremis* fell from 44 per 10 cm^2 in May 1974 to 7 per 10 cm^2 in June and rose again in July to 40 per 10 cm^2. Although there was little change in water temperature, this abnormal density drop in June may be reflective of the drop in sediment surface temperature and/or surface water salinity and/or sediment surface salinity (Table 50; Figure 16). The increase in numbers of copepods from June to July cannot be explained at present. Sediment surface temperatures fell to the lowest values in December 1972 (-0.85°C), January 1973 (-0.25°C), February 1973 (-1.1°C), November 1973 (-1.0°C), and January 1974 (-0.8°C). Copepods were present in all collections made on the above dates, and numbers of individuals were lowest at these periods with the exception of January 1973 (see comments above for this month). In general, changes in densities of *H. uniremis* were observed to be more reflective of the changes of sediment surface temperatures than changes of water temperatures.

The harpacticoid genus *Platychelipus* is reported to have a mid-range of salinity tolerance. Lang (1948)[58] found *Platychelipus laophontoides* able to withstand salinities as low as 8°/₀₀. Barnett (1968)[35] reported fluctuation in salinities of interstitial waters following periods of hot sun or heavy rains at low tide. He reported *P. laophontoides* able to tolerate salinities between 18-56.5°/₀₀ on a mudflat, and *P. littoralis* able to tolerate very low salinities. *Harpacticus uniremis* is apparently also tolerant to low salinities, but this species does not withstand salinities approaching that of freshwater (1-7°/₀₀; Feder, unpublished data). This copepod is found primarily in the first few centimeters of sediment in Port Valdez where salinities are consistently higher than that found in the overlying sea water and, in fact, sediment salinities never fell below 18°/₀₀ during our investigation (Table 50; also see Green, 1968[30] and Leppäkoski, 1968[19] for discussions on similar sediment-overlying sea water relationships). The limited salinity data available suggests that this parameter is not a limiting factor in the biology of *H. uniremis* in Port Valdez.

The seasonal cycle of primary productivity in Port Valdez appears to resemble other marine systems of similar latitudes. In general, a large bloom of phytoplankton and a maximum amount of organic matter are produced in the spring (Goering *et al.*, 1973)[79]. Muus (1967)[41] observed an increase in production of benthic diatoms in Danish estuaries in the spring and summer; in general, this increase followed temperature rather closely. A similar increase of benthic diatoms was noted in Port Valdez in the spring (Feder and Jewett, unpublished observations). Nearly all harpacticoid copepods feed on diatoms (Green, 1968[30]; McIntyre, 1969[36]; Muus, 1967[41]; Perkins, 1974[76]; R. Hamond, Zoology Department, Melbourne University, Australia, personal communication), and *Harpacticus uniremis* was observed feeding on chain-forming diatoms on 29 March 1975 (personal observation). The greatest densities of *H. uniremis* found on Dayville Flats were associated with increased production of diatoms and filamentous algae on the mudflat surface. Thus, abundance and distribution of harpacticoid copepods seem to be closely associated with seasonal abundance and distribution of primary producers.

DISCUSSION

The only intensive investigations of reproductive cycles of inter-tidal harpacticoids elsewhere were carried out on sediment beaches in the British Isles (Barnett, 1970[65]; Lasker *et al.*, 1970[66]; Harris, 1972[71]). In a study of an intertidal mudflat, Barnett (1970)[65] found that two species of *Platychelipus* had distinct breeding periods in the spring. Lasker *et al.* (1970)[66]

found a distinct seasonal reproductive cycle in the benthic harpacticoid, *Asellopsis intermedia*, with the maximum percent of ovigerous females occurring in May. Harris (1972)[71] found distinct reproductive periods in most of the ten harpacticoid species he examined with the majority of them breeding in summer months. Coull and Vernberg (1975)[43] examined shallow-subtidal harpacticoid copepods from a North Carolina estuary. They found that the dominant copepods were in a reproductive state all year whereas the less abundant species had distinct seasonal reproductive periods. The most common harpacticoid species found in Port Valdez, *Halectinosoma gothiceps*, also appeared to be in a reproductive state throughout the year (Section VI). Other authors (Barnett, 1968[35]; de Bovée and Soyer, 1974[55]; McIntyre, 1969[36]; Muus, 1967[41]; Perkins, 1974[76]; Straarup, 1970[47]) have examined seasonal density cycles of harpacticoids, and found the copepods to be most abundant in summer months and less dense in winter months. *Harpacticus uniremis*, a less common species in Port Valdez (see Section VI), has a distinct seasonal reproductive period with the maximum number of ovigerous females occurring in late winter and early spring (Figures 15 and 16). In the months with the greatest densities of copepods (summer), primarily adult, non-ovigerous females were present. Conversely, the months with lowest copepod densities (fall and winter, and early spring) typically had a more heterogeneous composition (Table 48; Figure 15). Copepodid maturation, the appearance of males in the population, and copulation took place primarily in late winter and early spring. Males typically disappeared from the population in May. Only adult females, presumably carrying spermatophores, remained throughout the summer. The numbers of these females declined precipitously in the fall, and the population of copepods generally remained low throughout the winter.

Most intertidal harpacticoids demonstrate some degree of differential horizontal distribution of specific life-history stages and/or members of the entire population. The selection process is undoubtedly a complex one, and presumably involves interactions with such factors as sediment-particle size, temperature, salinity, exposure time at low tide, diatom production, biological competition and predation. Barnett (1968)[35] studied the harpacticoid copepods of a mudflat in Southhampton, England and found a distinct zonation of species with tidal height. He took regular quantitative core samples from three sites in the intertidal zone. Two species of *Platychelipus* were found with *P. littoralis* most abundant at the upper level and *P. laophontoides* at the lower intertidal site. Both species were found at the mid-tidal site in roughly equal numbers. Other species of harpacticoid copepods have also been shown to be more abundant at specific tidal heights (Eltringham, 1971)[80]; for example, *Stenhelia palustris* is most frequently found high up on the shore while *Harpacticus flexus* and *Canuella furcigera* have their centers of abundance at the lower levels . Harris (1972)[74] examined the horizontal distribution of the harpacticoid *Evansula pygmaea* on a beach in Whitsand Bay. He observed no significant difference in the numbers of this copepod along a 175 m transect extending to mean low water spring tide but numbers were somewhat greater in the vicinity of mean low water neap. Results obtained in a Newman-Keuls multiple comparison test on mean numbers of *H. uniremis* at each of eight tidal levels at Dayville Flats on 29 March 1975 likewise showed no significant difference ($\alpha = 0.05$) between means. This analysis indicates that this species is widely dispersed on the mudflat. However, somewhat greater numbers were recorded between +0.5 m and -2.4 m (Table 51). The apparent contradiction of the test of significance for the transect data with the finding of greater numbers of copepods at certain stations along the transect is explained by the patchiness of the harpacticoid fauna in the area (Section VI). Such patchiness resulted in high variability between samples at each level. That some significant aggregation of one life-history stage (ovigerous females) of *H. uniremis* does take place on Dayville Flats has been demonstrated previously (see Reproduction in this Section). Harris (1972)[71] reported a similar difference in reproductive activity with tidal height for two species of harpacticoid copepods on a beach in England. He showed that the percentage of ovigerous females of each species tended to decrease at the upper and lower limits of their intertidal range. The selection of particular tidal levels by egg-bearing harpacticoids is probably an important factor in controlling the optimum intertidal distribution of the adults.

TABLE 51

TOTALS, MEANS AND STANDARD DEVIATIONS OF *HARPACTICUS UNIREMIS* COLLECTED AT EIGHT TIDAL HEIGHTS AT DAYVILLE FLATS, PORT VALDEZ ON 29 MARCH 1975. THREE 100 cm^2 SAMPLES ARE REPRESENTED AT EACH TIDE LEVEL.

	-4.0 m	-2.4 m	-1.0 m	-0.5 m	0.0 m	0.5 m	1.5 m	3.0 m
Total	15	52	32	72	93	42	16	11
Mean	5.0	17.3	10.6	24.0	31.0	14.0	5.3	3.6
Standard Deviation	2.65	23.12	3.06	18.03	16.70	6.56	1.53	2.31

Seasonal effects tend to be more marked in the intertidal zone since the fauna there is exposed to greater stresses than that encountered elsewhere in the marine environment. The drastic decrease in copepod numbers on the Dayville tidal flat at certain seasons probably reflects such stresses, and organisms there may undergo considerable mortality and/or move out of the region of stress at this time. Subtidal samples obtained at Jackson Point in Port Valdez from September 1970 through September 1972 (using multiplates and rock-filled baskets exposed for two to four months) yielded low densities of *Harpacticus uniremis* during cold months (J. W. Nauman and D. R. Kernodle, U.S. Geological Survey, personal communication). These data suggest that *H. uniremis* does not undergo substantial subtidal migration during this period. Harpacticoid copepods studied elsewhere undergo vertical migration into the sediment during cold periods of the year (Harris, 1972)[74]. Surface sediments in Port Valdez freeze at low water in the winter, but samples taken monthly to 8 cm in depth consistently demonstrated that approximately 95% of the meiofauna inclusive of copepods, were located in the upper three centimeters (Table 44, Section VI). A similar shallow distribution of harpacticoids at all seasons of the year was shown for individuals living on an English mudflat (Barnett, 1968)[35]. Presumably in both situations, copepods were restricted to the surface layers because of a rapid decrease in the interstitial oxygen below the mud surface; in sediments of Port Valdez interstitial oxygen is restricted to the upper three centimeters only (Section IV). Thus, it appears that the drastic decrease in numbers of copepods on the Dayville Flats in fall and winter can be best explained in terms of seasonal mortality only.

SECTION VIII

CRUDE OIL IMPACT ON PORT VALDEZ TIDAL FLAT SEDIMENT CHEMISTRY

INTRODUCTION

As part of the experimental program designed to assess the impact of Prudhoe Bay crude oil on sediment chemistry, meiofauna and the clam *Macoma balthica* in Port Valdez, a series of oil-additive experiments were performed on the tidal flats south of Ammunition Island (Section IV, Figure 1). The methodology and biological results of these experiments are described in Sections IX, X and XI; the depositional and geochemical environment of the experimental area are characterized in Section IV. It is primarily the purpose of this chapter to describe the perturbations on the sediment geochemistry at the mid-tide (0.0 m) experimental site following additions of varying concentrations of Prudhoe Bay crude oil.

METHODS

A total of 16 sediment samples, taken from plots exposed to Prudhoe Bay crude oil at various concentrations and lengths of time in conjunction with biological experiments in the field (for details of oil ammendment procedures refer to Sections IX, X and XI), were chemically analyzed to assess the short-term impact of oil on the sediment trace-element chemistry and organic carbon content. The procedure for the quantitative elemental analysis of oil-impacted sediments was identical to that adopted for the baseline element analysis on gravel-free sediments (Section IV).

RESULTS - DISCUSSION

One of the significant outcomes of the present study is the establishment of the fact that the surficial and near surficial (up to 16 cm from the top) sediments of the Port Valdez tidal flats at the site of our intensive studies (0.0 m tide level) are generally poor in organic carbon, and thus plausibly also in organic matter (see Section IV for further discussion). This finding was somewhat of a surprise, taking into account the ready source of organic matter to most of the tidal flat area. Some possible explanations for this unusual situation have been dealt with in Section IV. It has also been observed, contrary to expectations, that there is no significant increase in organic carbon in the sediments of the above tidal flat region following the exposure of the latter to various dosages of Prudhoe crude oil (Table 52). This may be explained in terms of two possibilities: (1) first, it is possible that there has been rapid physical removal of crude oil from the sediment surfaces, chiefly by the ebbing tide. Presumably, such a process of crude oil scavenging from the tidal flat is favored by the low air temperatures generally prevalent in the Valdez area. It is believed that, under low temperatures, the rate of evaporation of crude oil from the tidal flat will be relatively slow. As a result of this, it might be expected that the viscosity of Prudhce Bay crude oil would be maintained sufficiently low so that it would float out with the ebbing tidal waters. Further, it is held that because of the prevalence of an extensive tidal range, it would be expected that high turbulence at the mid-tide level would frequently occur, which in turn would favor resuspension and eventual tidal removal of any Prudhoe Bay crude oil that might have initially deposited on the tidal-flat surface; (2) the second explanation concerns the possible prompt bacterial degradation of crude oil. On the basis of the low organic carbon contents documented in the baseline tidal flat sediments of the mid-tide regions of all beaches examined (Section IV, Tables 8 and 9; this Section, Table 52), it would first seem that bacterial degradation of any additional influxes of hydrocarbon, at least on a limited scale, might be expected to take place. However, it is doubtful if such biodegradation does, in fact, take place. Norrell and Johnson (1975[81]) (also see Section IX) have shown in the study area south of Ammunition Island (Section IV, Figure 1) that a low bacterial biomass is present and that this biomass does not respond to *in situ* additions of Prudhoe Bay crude oil, although the bacteria do respond to *in vitro* oil additions (sediments mixed mechanically with oil in the laboratory). Further, it might be expected that bacterial sulfate reduction would be enhanced by crude oil in the presence of the abundant dissolved interstitial sulfate and the existence of anoxic conditions in the subsurface tidal flat sediments. The fact that no measurable increase in dissolved H_2S was observed, subsequent to oiling of the sediments,

TABLE 52

CARBONATE, ORGANIC CARBON, AND TOTAL CARBON CONTENTS IN BASELINE AND OIL-IMPACTED SEDIMENTS OF ISLAND FLATS. ALL PERCENTAGES ARE ON A GRAVEL-FREE, DRY WEIGHT BASIS. FOR DETAILS ON THE DOSAGES OF PRUDHOE CRUDE OIL WHICH WERE ADDED TO VARIOUS SEDIMENTS REFER TO TABLE 53.

Sample No.	$CO_3^=$ %	Org. C %	Total C %[a]
VLDZ10/73-1	0.76	0.268	0.420
VLDZ10/73-2	1.02	0.060	0.300
VLDZ10/73-7	1.64	0.070	0.398
VLDZ10/73-8	1.01	0.023	0.225
VLDZ10/73-9	1.90	0.105	0.485
VLDZ-OIL-1	1.64	0.057	0.385
VLDZ-OIL-2	1.01	0.053	0.255
VLDZ-OIL-3	0.76	0.201	0.355
VLDZ-OIL-4	0.63	0.054	0.180
VLDZ-OIL-5	1.14	0.110	0.338
VLDZ-OIL-6	1.25	0.060	0.310
VLDZ-OIL-7	0.89	0.037	0.215
VLDZ-OIL-8	1.01	0.153	0.355
VLDZ-OIL-9	1.38	0.077	0.353
VLDZ-OIL-10	1.14	0.146	0.368
VLDZ-OIL-11	1.25	0.080	0.330
VLDZ-OIL-12	1.14	0.150	0.378
VLDZ-OIL-13	1.72	0.075	0.420
VLDZ-OIL-14	1.60	0.085	0.405
VLDZ-OIL-15	1.75	0.018	0.400
VLDZ-OIL-16	2.95	0.180	0.410
VLDZ-OIL-17	1.15	0.130	0.360

[a] Organic plus inorganic carbon content. VLDZ-OIL series of samples were oil-impacted; the rest of the 5 samples are baseline representative sediments.

is considered strong additional evidence suggesting lack of bacterial degradation of Prudhoe crude oil on the tidal flats. In conclusion, the lack of any increase in organic carbon in sediments following their exposure to various dosages of Prudhoe Bay crude oil is most plausibly attributable to prompt physical removal of the oil from the tidal ecosystem by ebb tides.

Comparison of the sediment chemical data prior to and subsequent to the oiling of sediments (Section IV, Tables 11 and 12; this Section, Table 53), does not show any increase in trace element contents in the oiled sediments. Surprisingly, on the other hand, most of the oiled sediments have slightly lower values of trace elements than in the baseline samples. Besides, for any suite of sediments to which Prudhoe Bay crude oil was added, the same number of times no progressive increase in trace element contents were noticed in those sediments which were subjected to relatively higher dosages of crude oil. The sample VLDZ-OIL-16 was the only oiled sediment which showed a slight relative increase over other oiled sediments in the contents of Cu and Zn (Table 53). A slight overall increase in Cu and Zn concentrations in sample VLDZ-OIL-16 is understandable as this sediment was the only one exposed to a continuing chronic oil dosage over the experimental period.

The general lack of an increase in heavy metal concentration in the tidal flat sediments, subsequent to the oiling experiments, may be explained in either or both of the following ways: (1) As suggested earlier, it would seem plausible that the portion of crude oil which initially deposits on the tidal flat surface is promptly removed by subsequent ebb tides. Thus, any heavy metals chemically complexed with the crude oil are also quickly removed from the tidal flat ecosystem; (2) the second explanation takes into consideration the possibility that at least some portions of the total heavy metals associated with the crude oil would be dissociated, subsequent to the deposition of the oil on the tidal flat and prior to complete removal of it by tides. In the freed state the heavy metals would then be exposed to the surrounding muddy sediments, with possibilities of getting fixed by the predominant constituent of the muds, the clay minerals, via adsorption/ion exchange process. As a result of this it would seem probable that any additional influxes of heavy metals, released

TABLE 53

TRACE METAL CONCENTRATIONS (IN PPM) OF GRAVEL-FREE TIDAL FLAT SEDIMENTS OF PORT VALDEZ, SUBSEQUENT TO IMPACTION WITH PRUDHOE CRUDE OIL (SEE FIG. 2 FOR STATION LOCATIONS)

Sample No.	Conc. (ppm) of oil added	No. Times oil added	Collection date	Cu	Pb	Zn	Ni	V
VLDZ-OIL-1A	500	1	7-08-74	34	21	110	58	185
VLDZ-OIL-1B	500	1	7-08-74	33	21	90	60	185
VLDZ-OIL-1C	500	1	7-08-74	32	19	90	61	175
VLDZ-OIL-2	1000	1	7-08-74	38	20	90	67	190
VLDZ-OIL-3	2000	1	7-08-74	36	20	90	62	195
VLDZ-OIL-4	500	2	7-19-74	38	21	90	63	185
VLDZ-OIL-5	1000	2	7-19-74	35	16	80	58	195
VLDZ-OIL-6	2000	2	7-19-74	32	23	90	63	195
VLDZ-OIL-7	500	3	8-02-74	34	19	80	59	200
VLDZ-OIL-8	1000	3	8-02-74	37	21	100	70	215
VLDZ-OIL-9	2000	3	8-02-74	39	25	90	69	190
VLDZ-OIL-10	500	4	8-18-74	42	22	100	67	195
VLDZ-OIL-11	1000	4	8-18-74	37	20	90	60	190
VLDZ-OIL-12	2000	4	8-18-74	41	22	100	68	210
VLDZ-OIL-13	500	5	9-15-74	45	27	100	65	190
VLDZ-OIL-14	1000	5	9-15-74	40	22	105	67	180
VLDZ-OIL-15	2000	5	9-15-74	40	21	90	67	215
VLDZ-OIL-16[a]	200	b	9-15-74	53	26	125	77	205
VLDZ-OIL-17	0	0	9-15-74	66	22	97	85	255

[a] Sediment subjected to chronic oil dosages.

[b] Sediment was subjected to a number of oil dosages of 200 ppm on the following dates:

June 19,20,21,22, and 23 July 3,4,5,6,7,20,21,22,23,24, and 25 August 16,17,18,19, and 20 from the crude oil degradation, will eventually be immobilized within the tidal flat deposits. Assuming that there is some such dissociation of metals from the crude oil, it is felt that any subsequent heavy metal-clay mineral bonding probably would be of no significant consequence quantitatively. This contention is based on the fact that the clay mineralogy of the tidal flat muds at the site where crude oil was added, consist solely of chlorite and mica (or so-called "illite"). As mentioned earlier both of these minerals are presumably of the most stable high temperature/pressure polytypes, which probably have been subjected to almost no chemical weathering. Such a clay mineral suite is typically encountered in contemporary glacial flour derived from primary rocks (Kunze *et al.*, 1968[82]; Mueller and Naidu, in press[83]). It is contended that a sediment suite dominated by a clay mineral assemblage similar to the above will be expected to have relatively high electrostatic charges per unit-cell-layer, and as such presumably will also have limited capacities for interlayer ion exchange for heavy metals as well as hydrocarbons. In fact ethylene glycol solvation of all the above clay samples has shown no detectable interlayer expansions. In such a situation it would seem improbable that any such heavy metals that are dissociated from Prudhoe crude oil will be incorporated by the tidal flat muds to a significant extent. Therefore, it is not surprising to note that there is no increase in heavy metal concentrations in the oiled sediments. It is assumed that any heavy metals not sequestered by the clays are swiftly removed from the tidal flat ecosystem by the ebb tide. Those portions of the metals which escape such tidal removal are believed to be eventually incorporated within the sediment interstitial spaces. However, the amounts, if any, of these immobilized metal portions in case of all, except possibly one, of the oiled sediments (i.e. the chronically oiled deposit VLDZ-OIL-16) are too small to be quantitatively assessed and are, therefore, not exemplified in the chemical data of oiled sediments.

SECTION IX

THE EFFECTS OF OIL ON THE MICROBIAL COMPONENT OF AN INTERTIDAL SILT-SEDIMENT ECOSYSTEM IN PORT VALDEZ, ALASKA

VALDEZ SEDIMENT BACTERIOLOGY

Bacteria are often considered to be the basis of food chains in marine sediments. Zobell and Feltham (1938)[37] showed that certain marine invertebrates used bacteria as food. Perkins (1958)[84] concluded that many mud ingesting feeders were, in fact, feeding upon bacteria adhering to sand grains and to detritus, and McIntyre *et al.* (1970)[85] reported on the role of bacteria as a source of the protein and energy flowing through a sand ecosystem. In their studies of a flatfish nursery ground, McIntyre and Murison (1973)[40] concluded that the meiofauna feed mainly on bacteria and diatoms attached to sand grains and in the interstitial water. They were able to show that a substantial part of the meiofaunal carbon budget was supplied by bacteria and that a crucial factor in maintenance of the ecosystem was the delivery of soluble organics to the bacteria by movement of water through the sediment. Fenchel (1969)[86] details the interrelationships that exist between various biotic compartments, including bacteria, in oxidized sand in marine ecosystems.

The attachment of bacteria to sand grains and the relative populations of bacteria on the grains and in the interstitial water has been extensively studied by Meadows and Anderson (1968)[87]. Their studies suggest that, because most of the bacteria are attached to the sand grains in microcolonies, the sediment acts to hold the bacterial population in place and that movement of fluid through the sediment is necessary for the delivery of nutrients to the bacteria. Furthermore, Steele *et al.* (1970)[88] report that drainage and sublittoral pumping through sand beaches with mean grain diameter of 250 μ may be the dominant mechanism for supplying oxygen and soluble organic matter to the bacteria adhering to the sand grains.

In a well sorted, wave-washed, and oxidized beach ecosystem, the size of the bacterial poplulation was strongly, but negatively, correlated with mean grain size. Although bacterial biomass was strongly correlated with total carbon and nitrogen, the bacterial carbon was estimated to account for only 1.2% of the total carbon, and 2.5% of the total nitrogen, and no correlation was observed between bacterial biomass and oxidation state (as Eh) of the sediment (Dale, 1974)[89]. Dale further concluded that the strong statistical relationships are ultimately traceable to the dominant influence of the waves and tides on the properties of the intertidal sediments and that a statistically simple relationship may exist between bacterial biomass and sediment properties.

Cummins (1974)[90] presents evidence that, in a fresh water system, the microbes on particulate organic matter not only play a role in reducing the size of the particles, but also serve as the major food source for stream invertebrates. He concluded that the microbial biomass layer is at least as important a food source as the particles themselves, and that development of the bacterial layer is dependent upon the chemical properties of the particles. The final embedding of these particles in sediment appears to be necessary for their eventual conversion to dissolved organic matter and for return to the water ecosystem as dissolved, rather than particulate, nutrients.

The ability of crude oil to supply oxidizable soluble organic material to bacterial populations in marine sand ecosystems has been shown in several studies. Generally, the oil is able to cause an increase in bacterial biomass when added over prolonged periods, but does not permanently affect the size of, or composition of, the bacterial population when added only once, as would occur from a spill. Laboratory studies using artificially produced sand systems with a mean grain size of 350 μ (Bloom, 1970)[91] and 250 μ (Johnston, 1970)[92], as well as studies of spills on natural beach systems at San Francisco Bay (Cobet and Guard, 1973[93]; Guard and Cobet, 1973[94]) and in beach communities affected by the Torrey Canyon spill on the Cornish Coast (Gunkel, 1968)[95], are in agreement with the reports of Steele *et al.* (1970)[88] and Meadows and Andersen (1968)[87] discussed above. Increased oxygen uptake in sand columns made with Nobska Beach, Woods Hole, Massachusetts, sand of 350 μ mean particle diameter was shown when the columns were flushed with sea water contaminated with Kuwait Crude oil plus the dispersant "Corexit 7664" (Enjay Chemical Company) and with dispersant alone (Bloom, 1970)[91]. This suggests that the dispersant alone, or in combination with oil, had no obvious deleterious effects on either the meiofaunal population or the bacteria. Bleakley and Boaden (1974)[96], however, report that the dispersant Lissapol N produces some morbidity in copepods (Order: Harpacticoida) at as little a concentration as 1 ppm, although an observed decline in morbidity may "reflect the recovery of the surviving meiofauna probably associated with the bacterial degradation of surfactant."

The sediment ecosystem on some sediment beaches studied in Port Valdez is of different physical and physiological characteristics than those reported on above, and is extensively characterized in this report (Section IV). The surficial sediment is composed of fine glacial silt, deposited at an annual rate of about 1.67 cm/year, and having a mean particle size of only 4 to 16 μ. The particle size is uniform to a depth of 5 cm and, because there is typically no effective wave action, there is no apparent sorting of the particles on the surface. The salinity of the interstitial water is always higher than the overlying tidal waters, often by a factor of at least two, even under conditions of heavy rainfall (up to 2 m of rain may occur during the period from July to October). The study area is traversed by several streams from nearby snowfields and surface runoff of the rainwater is constant and typical. The sediment contains no dissolved or precipitated sulfide (except under heavy algal mats), from 0.1 to 0.3 ppm iron (with no gradient with depth). There is typically less than 0.2% by weight of organic matter in the sediment, and the interstitial water has a constant pH of between 7.2 and 7.4. The low organic content and the absence of animal remains in the sediment suggest that deposited organisms are either removed by rapid digestion on the surface or by tidal action. Thus, very little of the organic matter becomes embedded in the sediment. The absence of detectable sulfide suggests a highly oxidized and aerobic environment (Fenchel, 1969)[86] (Section IV).

The upper two to three centimeters of the sediment in Port Valdez appear to be the biologically active layers. Examination of the meiofaunal component of the ecosystem in the study area at Island Flats (see below for location of area) indicates that most of the organisms are located in the upper three centimeters of sediment and that the numbers of organisms contained in the upper horizon range from 845 to 1934 per 10 cm^2. Sixty-one percent of these meiofaunal organisms were nematodes with 31% of them harpacticoid copepods (Section VI).

A major objective of this study was to estimate the size and activity of the bacterial population in Valdez intertidal sediments and to determine the effect of oil on this population. The presence of various sulfur bacteria was also examined because of their association with both marine environments and with oil deposits. Typically, in highly oxidized marine sediments, they form ecosystems that are of great complexity and of almost universal distribution (Fenchel, 1969[86]; Fenchel and Riedl, 1970[97]). Sulfur bacteria are almost always associated with oil deposits, although their actual role in the oxidation of oil or in oil synthesis is not known (Guarraia and Ballentine, 1972)[98]. Kusnetzov (1967)[99] does report an instance in which oil became the source of energy for sulfate reducing bacteria, with hydrogen sulfide sometimes being produced at the rate of 0.2 mg/ℓ/24 hrs.

MATERIALS AND METHODS

Sampling and Site Preparation

Sampling for bacterial analysis were collected during the summer months of 1973 and 1974 from an intertidal zone near Port Valdez, Alaska, located on Valdez Arm of Prince William Sound, in conjunction with the meiofaunal studies described in Sections VI and X. Specifically, samples were taken from the undisturbed site at Island Flats (Section IV, Fig. 1), an oil seepage site at Old Valdez, Alaska (produced by the burial of an oil tank during the 1964 earthquake), and from under algal mats on the Island Flats Site.

The 1973 samples were collected to determine the comparative size of the bacterial populations in open sediment, sediment directly under (decaying) algal mats, and in sediment exposed to continuous oil seepage from the buried oil tank at Old Valdez.

On 18 June 1974, four sets of 25 glass rings (see Section X for further details on methodology) approximately 15 cm in diameter and 4 cm in height were placed in the sediment of the intertidal study area on Island Flats. These rings, while only slightly immersed in the sediment, were not displaced by daily tides. Each set of 25 rings comprised a separate "site", designated as Control (C), 500 ppm, 2000 ppm, and Chronic (CH). The rings in the 500 ppm site each received two equal applications of 500 ppm of Prudhoe Bay Crude Oil on two consecutive days during each low tide series of the summer of 1974 (for a total of 1000 ppm at each tidal series). Similarily, the rings of the 2000 ppm site received 4000 ppm of oil at each tidal series. Each ring in the Chronic (CH) Site received 200 ppm of oil on each of five consecutive days during each low tide series, for a total of 1000 ppm oil per tide series. The rings within the Control (C) Site were never oiled.

During each low tide interval throughout the sampling periods, five to six sediment cores were taken to a depth of 2 cm from each site. Not more than one core was taken from each ring and the sediment within any one ring was only sampled once for bacterial analysis. (The remaining sediment was used for meiofaunal studies.) When sampling was outside the sites containing the glass rings, cores were taken randomly from apparently homogenous areas.

Sampling dates were dependent upon tide levels, and specific samples were taken at least one tide series after the previous addition of oil. For example, sediments samples on 3 July 1974 received only one series of oil application (on 19, 20 June) while those sampled late in the season (15 September 1974) had been oiled on five previous low tide exposures. The samples taken from the Old Valdez site were considered to represent constantly oiled sediments. The sampling and oil application schedule is shown in Table 54.

The individual cores, from replicate rings, were taken using a steel corer approximately 4 cm in diameter and the contained sediment immediately expressed into a sterile Whirlpak bag in such a way that no fluid or sediment was lost. The samples were transported and stored on ice or under refrigeration (4°C) for analysis in the laboratory at Fairbanks. In all cases, processing of the cores was begun no later than 48 hours after sampling. Each of the five replicate cores was analyzed separately and the results averaged for each site.

TABLE 54

OIL AMMENDMENT AND SAMPLING PROTOCOL FOR EXPERIMENTS OF SUMMER 1974

DATES ON WHICH OIL WAS ADDED			DATES ON WHICH SAMPLES WERE TAKEN
Control Sites	Chronic Sites	500 & 2000[a] Sites	
Samples taken for baseline - control data, no previously oiled samples.			6/18
None Added	19-23 June[b]	19, 20 June	7/3
None Added	19-23 June 3-7 July	19, 20 June 3, 4 July	7/20
None Added	19-23 June 3-7 July 20-24 July	19, 20 June 3, 4 July 20, 21 July	8/5
None Added	19-23 June 3-7 July 20-24 July 1-5 August	19, 20 June 3, 4 July 20, 21 July 2, 3 August	8/26
None Added	19-23 June 3-7 July 20-24 July 1-5 August 16-20 August	10, 20 June 3, 4 July 20, 21 July 2, 3 August 16, 17 August	9/15

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[a] 500 or 2000 ppm oil added, in equal amounts, on the dates shown. See Section X for further details on oil ammendment procedure.

[b] 200 ppm oil added on each day, inclusive of the dates shown. See Section X for further details on oil ammendment procedures.

Total Bacterial Population

Total aerobic bacterial populations were estimated by standard plate count-dilution methods (Meynell and Meynell, 1965[100]; Parkinson *et al.* 1971[101]) using Tryptone Glucose Extract Agar (Difco) prepared with filtered sea water taken from Port Valdez offshore waters and supplemented with 8 mg/l cycloheximide. All dilutions were made with filtered, sterile sea water from the same source. In every case, except the initial samples the sediment was allowed to settle for five minutes prior to dilution. All samples were counted in triplicate after ten days incubation at 10°C in the dark. Unless otherwise noted all incubations were aerobic and are reported as total "aerobic" counts. (See Sulfate reducer counts.)

Sulfur-Cycle Bacteria

Two methods were used to test for the presence of sulfate reducing bacteria. One method involved plating appropriately diluted samples from single cores, following the procedure described for total aerobic population counts except that, in this case, the medium consisted of Tryptone Glucose Extract Agar (Difco), 24 g/ℓ; Na_2SO_4, 5 g/ℓ; $FeSO_4$-$7H_2O$; 0.09 g/ℓ; and filtered sea water to 1000 ml (Aaronson, 1970)[25]. Plates were incubated in BBL Anaerobe Jars using CO_2 + H_2 gas packs. After 10 days incubation in the dark at 10°C, the plates were examined for blackened colonies (sulfate reducers) and total "facultative counts."

The second method of determining the presence of sulfate reducing bacteria involved using a liquid medium (Aaronson, 1970)[25], consisting of KH_2PO_4, 0.5 g/ℓ; NH_4Cl, 1.0 g/ℓ; sodium lactate, 6.0 g/ℓ; $CaCl_2$-$6H_2O$, 60.0 mg/ℓ; $MgSO_4$-$7H_2O$, 60.0 mg/ℓ; yeast extract, 1.0 g/ℓ; $FeSO_4$-$7H_2O$, 0.1 g/ℓ; sodium citrate $2H_2O$, 0.3 g/ℓ; $(NH_4)_2SO_4$, 7.0 g/ℓ; and filtered sea water to 1000 ml. The pH of the medium was adjusted to 7.5, before autoclaving. 1.0 g sediment samples from separate cores were placed in 70 ml sterile glass stoppered bottles or 5.0 g sediment samples from single cores were placed in 275 ml sterile glass stoppered bottles. The bottles were then filled to the brim and stoppered to exclude air. Samples were incubated in the dark at 10°C and examined periodically for blackening of the medium.

The production of H_2S by heterotrophic bacteria from organic sources was examined by subculturing heterotrophs on appropriate medium to detect hydrogen sulfide production. Every colony growing on or breaking the surface of the agar in selected plates used for total counts was picked and inoculated into sterile deeps of a solid medium consisting of Tryptone Glucose Extract Agar, 24 g/ℓ; L-cystine, 0.1 g/ℓ; Na_2SO_4, 0.5 g/ℓ; lead acetate, 0.3 g/ℓ; and filtered sea water to 1000 ml (Aaronson, 1970)[25]. Tubes were incubated at 10°C in the dark and were examined periodically for areas of black precipitation in the region of growth.

The presence of green photosynthetic sulfur bacteria was determined using the following medium (Larsen, 1952[102]; Aaronson, 1970[25]): NH_4Cl, 1.0 g/ℓ; KH_2PO_4, 1.0 g/ℓ; $Na_2S\text{-}9H_2O$, 1.0 g/ℓ; $MgCl_2$, 0.5 g/ℓ; NaCl, 2.0 g/ℓ; and filtered sea water to 975 ml. The pH was adjusted to 7.0, before autoclaving. After autoclaving and cooling of the medium, 2.0 g $NaHCO_3$ in 25 ml filtered sea water, previously sterilized by millipore filter, was added. Sterile glass stoppered bottles were inoculated with sediment and medium was added as described for use of the liquid sulfate reducer medium. Bottles were incubated in the light at 10°C and examined periodically for green colonies.

The presence of purple photosynthetic sulfur bacteria was determined as for green photosynthetic sulfur bacteria, except, in this case, 2.1 g/ℓ $Na_2S\text{-}9H_2O$ was used and the pH of the medium was adjusted to 8.0, before autoclaving (Larsen, 1952[102]; Aaronson, 1970[25]). Bottles were examined periodically for purple colonies.

A modified Winogradsky-type column technique (Fenchel, 1969)[86] was used to simultaneously determine the presence of "white sulfur" chemoautotrophic, sulfur oxidizing bacteria and of green and purple photosynthetic sulfur bacteria. The solid phase, consisting of $CaSO_4$, 10 g/ℓ; glucose, 1 g/ℓ; peptone, 1 g/ℓ; agar, 15 g/ℓ; and filtered sea water to 1000 ml, was added to large test tubes to a depth of about 4 cm. The liquid phase and inoculum, consisting of 20 ml of a 10^{-1} dilution of sediment in sterile filtered sea water, was added to the tubes, covering the solidified medium. Two sets of tubes were set up; in one set the sediment in the dilution was not allowed to settle before the 20 ml was dispensed over the medium; in the other set, the sediment in the dilution was allowed to settle for 10 minutes and only the resultant supernatent was dispensed over the medium. Tubes containing the unsettled dilution of sediment were incubated at 10°C in the dark and periodically examined for the presence of "white sulfur" bacteria. Tubes containing both unsettled and settled dilutions of sediment were incubated at 10°C in the light and were periodically examined for the the presence of "white sulfur" bacteria, and later for the presence of green and purple photosynthetic sulfur bacteria.

The presence of non-sulfur, photosynthetic bacteria (Athiorhodaceae) was determined using a liquid medium (Pratt and Gorham, 1970)[103], consisting of NH_4Cl, 1.0 g/ℓ; KH_2PO_4; 1.96 g/ℓ; K_2HPO_4-3HO, 3.33 g/ℓ; $MgCl_2$, 0.2 g/ℓ; NaCl, 2.0 g/ℓ; Bacto-Yeast Extract, 0.2 g/ℓ; Bacto-Peptone, 2.9 g/ℓ; and filtered sea water to 975 ml. After the medium was autoclaved for 20 minutes at 15 psi and cooled, 5.0 g $NaHCO_3$ in 25 ml filtered sea water, previously sterilized by millipore filtration, was added. Sterile glass stoppered bottles were inoculated with sediment and medium added as previously described. Bottles were incubated at 10°C in the light and were examined periodically for pink, orange or straw-colored pigmentation of the medium, or for pigmented colonies growing on the surface of the sediment.

A Most Probable Number (MPN) statistical dilution estimate of the number of Athiorhodaceae was made following standard MPN methods. The medium and culture conditions were as described above, except that, for each sample tested, triplicate aliquots of 10 ml, 1 ml, and 0.1 ml of a 1:1 dilution of sediment to medium were added to separate 16 x 125 mm test tubes. The tubes were then filled to the brim with medium and capped to exclude air. Incubation was as previously described for Athiorhodaceae.

An attempt was made to determine what percentage of colonies developing on total aerobic population plates were Athiorhodaceae. Colonies were picked from plates as previously described for bacteria producing hydrogen sulfide from organic sources and were inoculated into tubes containing liquid Athiorhodaceae medium. The tubes were incubated as previously described for Athiorhodaceae.

Oxygen Uptake by Sediment

Oxygen consumption rates of unamended, glucose supplemented, and oil-supplemented sediment were obtained by incubating homogenized sediment with appropriate supplements in Gilson Respirometer flasks. Sediment was prepared by removing visible remains of meiofauna and mixing with filtered sea water. In one experiment, the oxygen consumption rates were determined both before and after addition of glucose and oil, and calculated in such a way that the oxygen uptake obtained under each experimental condition could be compared directly. Specific experimental conditions are given with the results. Various combinations of sediment and sterile sea water were used in attempts to obtain maximum uptake rates. In all cases, triplicate flasks were run, the results averaged, and oxygen uptake reported as microliters of oxygen consumed per hour per gram of sediment ($\mu l\ O_2/hr/g$). The temperature coefficient (Q_{10}) was determined by comparing the rate of oxygen uptake at both 10°C and 20°C. Unless noted as otherwise, equilibration of flasks prior to uptake determination was between 12 and 18 hours, at the experimental temperature.

RESULTS

Table 55 shows the counts obtained, in colony-forming-units/cc of sediment (CFU/cc), for five replicate samples taken in 1973, with the standard deviations of the replicate counts shown in parentheses. The differences in counts of bacteria between the algae-covered site in the August sampling and the Oil Seep Site in the September sampling, when compared to controls, were found to be highly significant (P = less than 0.001); however, no other significant differences were observed, including the counts obtained from sediment that had been lightly oiled two months (four tide series) previously. Interestingly, the algae-covered site, which by the September sampling period had been subjected to freezing, no longer supported a larger bacterial population when compared to the bare sediment controls.

The data in Table 56 show the estimated size of the aerobic and facultatively anaerobic heterotrophic bacterial population, in colony forming units per gram of sediment, for all samples taken during the 1974 field

TABLE 55

PRELIMINARY SURVEY OF BACTERIAL BIOMASS IN SEDIMENTS FROM ISLAND FLATS STUDY AREA AND OIL SEEP SITE FROM OLD VALDEZ PRE-EARTHQUAKE OIL STORAGE AREA DURING 1973 SAMPLING SEASON

Sampling Sites	Sampling Dates 8/27/73	 9/27/73
	Bacterial Count, CFU/cc[a] of Sediment (x 10^3)	
Control Site	70 (34)	46 (37)
Oiled Site (Surface Application on 6/27/74)	70 (32)	ND[b]
Algae Covered	189 (43)	6 (16)
Old Valdez Seep	ND[b]	179 (59)

[a] CFU = Colony forming units/cubic centimeter.

[b] ND = Not determined.

TABLE 56

HETEROTROPHIC BACTERIAL COUNTS ON SEDIMENT SAMPLES FROM OILED AND CONTROL ISLAND FLATS SITES TAKEN DURING 1974 SAMPLING SEASON

SAMPLING DATES	NUMBER OF PREVIOUS OIL APPLICATIONS	COUNT CONDITION	HETEROTROPHIC BACTERIAL CFU/gm x10				DAILY SAMPLING MEANS	
			CONTROL	500 PPM	2000 PPM	CHRONIC	TOTAL	OILED ONLY
6/18/74	None	Sediment Suspended	675					
		Settled 30 Min.	361					
7/3/74	1[a]	Aerobic[b]	34	41	41	106	55	63
		Anaerobic	3	10	8	41	15	20
7/20/74	2	Aerobic	245	301	289	315	287	302
		Anaerobic	21	16	27	35	25	26
8/5/74	3	Aerobic	125	37	370	380	228	262
		Anaerobic	6	7	10	40	16	19
8/16/74	4	Aerobic	724	460	247	386	454	364
		Anaerobic	113	40	16	26	49	27
9/15/74	5	Aerobic	87	201	137	194	154	177
		Anaerobic	5	4	9	25	11	13
Overall Season Means		Aerobic	243	208	216	276	235	233
		Anaerobic	30	15	14	33	23	20

[a] Numbers of times oil was applied to sediment surface prior to sampling. In all cases sampling occurred at the next tide series after the oil application (see Material and Methods, Table 54).

[b] Refers to incubation of plates. Anerobic counts were obtained from sulfate reducing counts and are all colonies that grew, whether or not they produced blackened zones around the colonies (see Methods).

season. The results of a determination of the effects of sediment settling are also shown (18 June sample). These figures indicate that there is a loss of almost 50% of bacteria when the sediment is allowed to settle for 30 minutes before the dilution series is completed, suggesting that the major proportion of the bacterial population may be found on the sediment grains, rather than in the interstitial water. However, at the dilutions used, the amount of sediment present prevented accurate counting and the sediment was allowed to settle for 15 minutes in subsequent counting experiments. Also, the ratio of "aerobic" to "facultatively anaerobic" organisms is, with the exception of the 3 July sample, relatively constant at about 10:1 (from 8.1:1 to 15.4:1). Interestingly, the addition of oil to surface of the sediment, at all concentrations tested, including the chronic additions, had a small but consistent enriching effect on the size of the bacterial populations that could be detected, but not statistically supported, by plate counting methods. In fact, the lack of differences observed in the overall season means is striking, while, on the other hand, the change in the daily sampling means over the season suggests a seasonal pattern for the size of the bacterial biomass. The population seems to peak during August, followed by a gradual decline through September.

Sulfur Cycle Bacteria

Hydrogen Sulfide Producers - Sulfate Reducing Bacteria —

When the plating method for determining the presence of sulfate-reducing bacteria was used to estimate the presence of these organisms in Control Site sediment taken on 18 June 1975, no blackened colonies were observed on any of the plates (containing approximately 1,000 colonies) after 10 days of incubation at 10°C. When the same sediment samples were enriched for these organisms with selective media, similarly negative results were obtained. Three glass-stoppered bottles containing 275 ml of medium and two containing 70 ml of medium were inoculated with 5.0 and 1.0 g of sediment, respectively. After seven weeks of incubation at 10°C, all bottles showed heavy turbidity, but none showed blackening due to the production of hydrogen sulfide. At the end of 11 weeks incubation, only one bottle containing 275 ml of medium and 5.0 g of medium, showed evidence of hydrogen sulfide production.

Hydrogen Sulfide Producers - Aerobic Hydrogen Sulfide Production —

Table 57 shows, for four of the sampling days, the percent of cultures from each of the sampling sites which were able to produce hydrogen sulfide from an organic source. The mean number of colonies sampled from each series was 66, and the cultures were maintained until no change in the percent of positives was observed, or until approximately eight weeks, when dehydration precluded further use. Between 60 and 97% of the colonies sampled produced hydrogen sulfide within 52 days. While there is no significant difference between the control cultures and the cultures from the oiled sites, a slight seasonal increase is apparent. This is shown by the increase in the percentage of cultures showing H_2S production, and the time needed for that production to become visible.

Photosynthetic Sulfur Bacteria - Chromatiaceae (Formerly Thiorhodacae) and Chlorobiaceae (Formerly Chlorobacteriaceae) —

The photosynthetic sulfur bacteria were generally found to be present in only small numbers. Only two of three enrichments for the green sulfur bacteria (Chlorobiaceae) prepared with 5.0 g sediment were positive after seven weeks of incubation. After 11 weeks, all five-gram enrichments showed positive results, but the one-gram enrichments produced only three colonies of bacteria on the surface of the settled sediment. Enrichments for the purple sulfur bacteria (Chromatiaceae) were even less successful, producing only one colony of purple bacteria after 11 weeks enrichment from a total of 13 g of sediment. The long enrichment times precluded examination of late season samples and only the sediment collected on 18 June was enriched for the photosynthetic sulfur bacteria.

Purple Nonsulfur Bacteria - Rhodospirillaceae (Formerly Athiorhodaceae) —

In enrichment for the nonsulfur purple bacteria from 18 June sediment samples, all enrichments were positive within four weeks, and a Most Probable

TABLE 57

PERCENT OF COLONIES PRODUCING H_2S FROM ORGANIC SOURCES

Sampling Date[a]	Incubation, Days	PERCENTAGE OF COLONIES PRODUCING H_2S			
		Control	500 ppm	2000 ppm	Chronic
6/18	14	34	-	-	-
	31	67	-	-	-
	42	68	-	-	-
7/3	14	42	40	41	42
	35	74	56	47	70
	52	74	60	64	74
7/20	10	25	17	37	33
	28	95	94	94	79
	42	97	95	96	79
8/5	14	94	79	72	83
	28	97	84	82	88
	35	97	84	82	88

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[a] Samples taken from Island Flats in Summer of 1974.

Number Analysis was completed on sediment collected at the 20 July sampling period. After three weeks of incubation, most of the 10 ml inoculated tubes were positive, and after four weeks, tubes at all dilutions showed positive results. Table 58 shows the Most Probable Number Analysis for Rhodospirillaceae after four weeks incubation of enrichment cultures inoculated with aliquots of 1:1 suspension of sediment in filter-sterilized sea water. No attempt was made to determine if the enrichments were oxygen tolerant or if any were capable of converting sulfide into sulfur. Since the medium contained only organic additives, the sulfur transitions that may have occurred would be of sulfide contained either in the sea water or the sediment. However, since these sediments are especially low in sulfides (Section IV) it is doubtful that these organisms play any role in the sulfur cycle in Valdez silt sediments.

Micro-Aquaria Model Ecosystems

The ability of the microbial population in Valdez sediments to establish a sulfur cycle system, as described by Fenchel (1969)[86], was verified using Fenchel's micro-aquarium technique. The micro-aquaria were inoculated with both suspended sediment and aliquots of supernate from which sediment had been allowed to settle out. As suggested by the reduction in counts due to the settling of the sediment reported above, the aquaria inoculated with clear aliquots showed much delayed, if any, activity. Only one of five cultures showed any evidence of bacterial activity after three months incubation. However, cultures inoculated with suspended sediment produced changes consistent with those reported by Fenchel, although the changes were consistently delayed. After four weeks incubation in the light, the medium throughout the tube turned black, and by six weeks a dense band of growth was observed approximately one-third of the way down the liquid part of the column. This band slowly moved down the liquid column, causing the medium above the band to lighten to a cloudy gray color, while the medium below remained black. After 12 weeks, the band had moved to the bottom of the liquid phase and the entire liquid part of the column had lightened to a light gray. The solidified lower part of each column remained black, except for a thin layer of clear agar at the agar-liquid

TABLE 58

MOST PROBABLE NUMBER ANALYSIS OF ENRICHMENT CULTURES FOR RHODOSPIRRILLACEAE (FORMERLY ATHIORHODACEAE)

Sample	Number of Tubes Positive 10:1.0:0.1			MPN Per 100 ml of 1:1 Dilut.	Mean MPN 50 gm Sed	Mean, 95% Confidence Limits
Control	3	3	2	1100		
	3	3	1	460		
	3	3	2	1100	672	95 - 3140
	3	3	1	460		
	3	3	0			
500 PPM	3	2	2	210		
	3	2	2	210		
	3	1	1	460	257	140 - 945
	3	3	3			
	3	2	1	150		
2000 PPM	3	3	2	1100		
	3	3	2	1100		
	2	2	2		668	94 - 3011
	2	1	0	15		
	3	3	1			
Chronic	3	3	3			
	3	3	1	460		
	2	2	3		314	47 - 1616
	2	2	0	21		
	3	3	1	460		

interface. Identically prepared cultures, when incubated in the dark followed similar, but slower, patterns of changes, and after the 12 weeks of incubation the band of bacterial growth had only moved approximately three-fourths of the way down the liquid column. At no time, however, were bands of green or purple pigmented bacteria observed in the liquid column, although some pigmented forms were apparent in the settled sediment. The significance of these transitions are discussed by Fenchel (1969)[86] and in the Discussion.

Micro-Respirometry

Oxygen uptake was found to be very low; the observed rates being consistent with that which would be expected because of the observed low biomass present in the sediments. Initially, uptake rates were determined for 3 g of sediment at 10°C, but were later determined for 8 g of sediment at 20°C. To increase diffusion of gases into the sediments, they were routinely mixed with sterile sea water, bringing the volume up to that which could safely be used in the manometric flasks. Nevertheless, the rates obtained and reported here approach the lower limits of machine sensitivity and are included only because they are consistent with other data and with expected changes due to sediment amount, temperature effects, and added organic materials.

Oxygen uptake was found to be proportional to the amount of sediment used, over a range of 3 to 8 g of sediment, but constant when converted to oxygen uptake per hour per gram (µl O_s/hr/g) of sediment. The experiments reported in Table 59 indicate that sediments that have been chronically exposed to oil do not show increased O_2 uptake when compared to unoiled sediment control samples (Figure 17). However, the mixing of glucose with sediment *in vitro* did cause an increase in the rate of oxygen uptake (Figure 18). The increase in the rate of O_2 consumption was observed for each core and when averaged showed a doubling of uptake (Table 59).

When oil was mixed with sediment *in vitro* (as opposed to surface application *in situ*) and oxygen uptake measured 24 hours later, a two-fold increase in the rate of uptake was observed. Table 60 shows the results of

TABLE 59

OXYGEN UPTAKE BY SEDIMENTS ENRICHED *IN VITRO* WITH GLUCOSE AND BY *IN SITU* SURFACE APPLICATION OF OIL

Sample Date	Sediment Source	Core Number	Supplement	Rate of Uptake[a] μl O_2/hr/gm
6/18/74 (10°C)[c]	Control Site	1	None	0.56
			1.8 mg Glucose[2]	0.78
		2	None	0.45
			1.8 mg Glucose	0.89
		3	None	0.12
			1.8 mg Glucose	0.33
		Ave. of Cores	None	0.37
			1.8 mg Glucose	0.66
7/20/74 (20°C)	Control Site	1	None[d]	0.55
		2	None	1.00
		Ave.	-	0.77
	Chronically Oiled Site	1	None	0.46
		2	None	0.89
		Ave.	-	0.67

[a] Rate determined by averaging triplicate flasks prepared from each core.

[b] 0.5 ml of 0.02 M glucose added to reaction flasks containing 3.0 gms sediment and 3.0 ml sterile sea water after unsupplemented rate was determined. Final glucose concentration was 1.8 mg glucose/flask, or 0.277 mg/ml in reaction mixture.

[c] Temperature at which oxygen uptake rate was determined.

[d] Reaction mixture of 7/20 samples contained 5.0 gm sediment plus 3.0 ml sterile sea water.

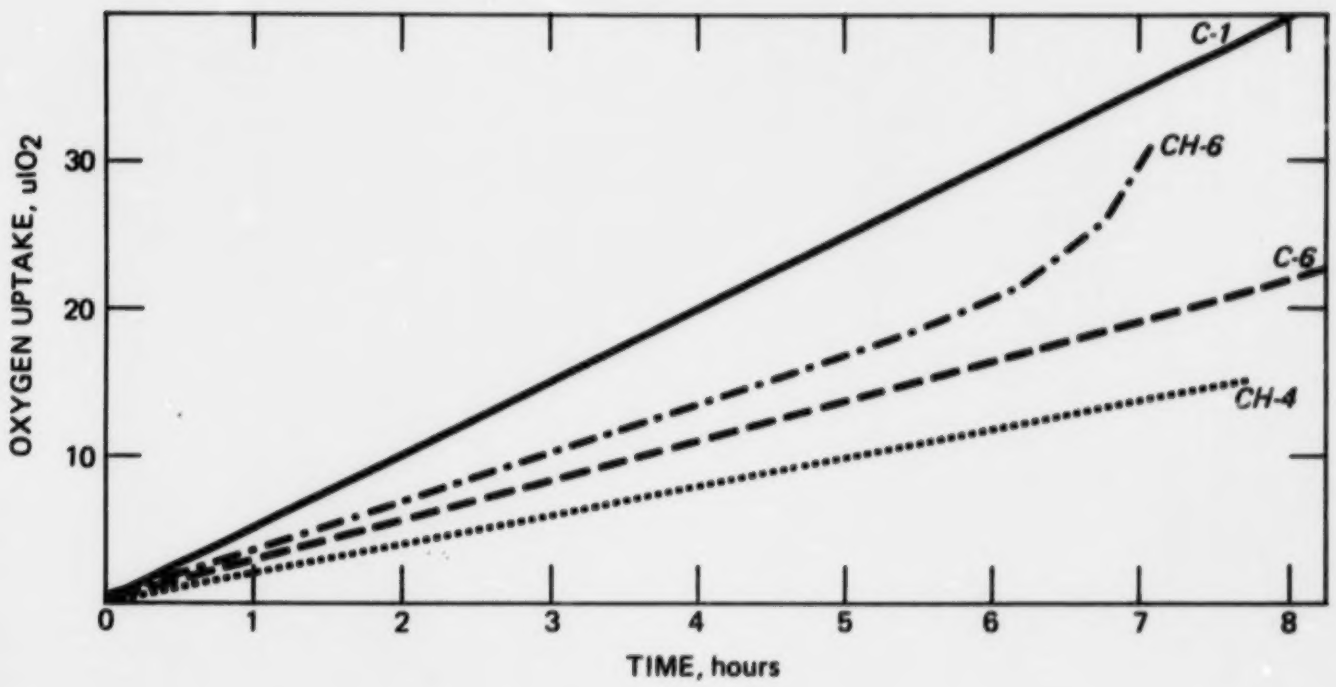

Figure 17. Oxygen uptake by unsupplemented sediments. C = control sediment. CH = chronically oiled sediment. Sample date: 20 July 1974. 5 g sediment and 3 ml of water per flask.

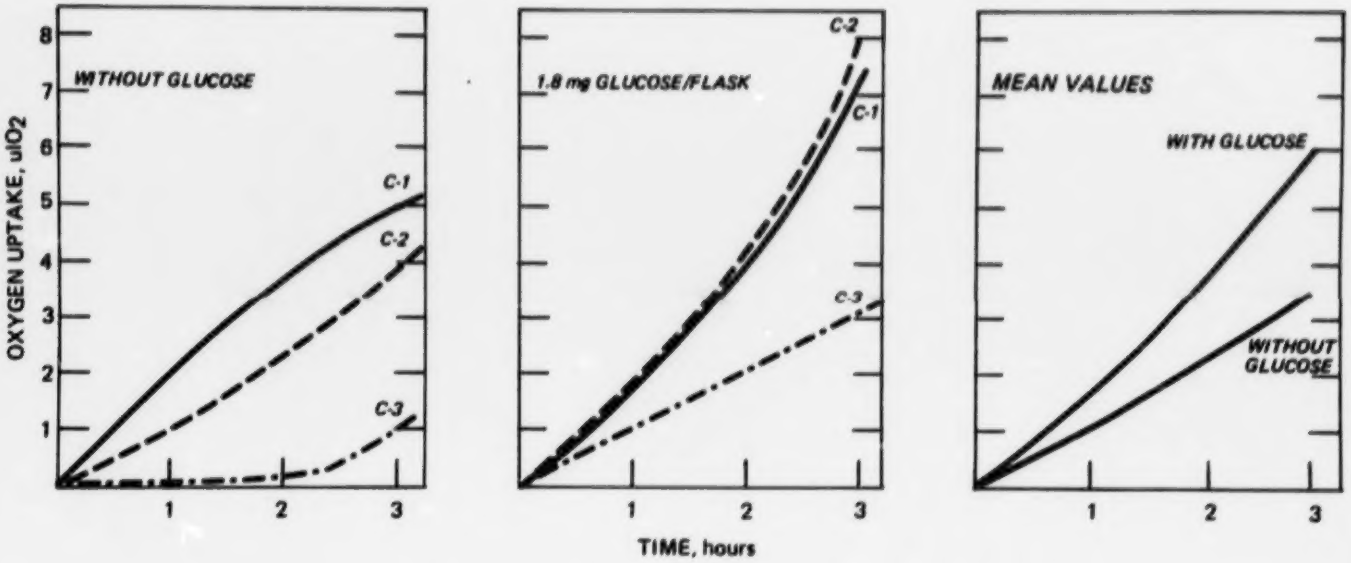

Figure 18. Oxygen uptake by glucose - supplemented control sediment samples (3 g of sediment and 3.0 m sea water per flask).

TABLE 60

OXYGEN UPTAKE BY CONTROL SITE SEDIMENTS ENRICHED *IN VITRO* WITH GLUCOSE AND OIL

	EXPERIMENTAL CONDITIONS		
	Series 1: Control Sediment	Series 2: Control Sediment	Series 3: Control Sediment
Reaction Mixture[a]			
Sediment, gm.	5.0	8.0	5.0
Sterile sea water, ml.	3.0	None	3.0

	RATES OF O_2 UPTAKE, μ/02/HR/GM			
	Series 1	Series 2	Series 3	Series 4
Average Initial Rate, before organic supplement. (N = 6 per series)	1.14	0.88	0.88	0.96
Average Glucose Enhanced Rate[b] (N= 3 per series)	1.66	1.80	1.76	1.74
Average Oil Enhanced Rate[c]. (N = 3 per series)				
After 2 hours	1.06	1.00	1.08	1.04
After 24 hours	2.53	2.07	1.54	2.04

---

[a] Shows reaction mixture before addition of supplements. All samples were collected on 8/16/74.

[b] Glucose (10 mg/flask: Final concentration to 1.25 mg/ml) was added to three reaction vessels and the uptake rate determined for three hours, following a two-hour equilibration.

[c] The rates shown were determined over two three-hour periods, beginning at 2 hours and again at 24 hours after the addition of 0.5 ml Prudhoe Bay Crude to the reaction mixture.

experiments designed to test the response of the sediment microbial population to "mixed-in" oil and glucose. In the experiments reported here, the glucose and oil was added to sediments after approximately four hours incubation in the respirometer and the resulting changes in uptake recorded. When the uptake was measured two hours after mixing glucose and oil with separate sediment samples, the glucose was observed to cause an increase in the rate of oxygen uptake, but the uptake rate of the oil-amended sediment did not change significantly. After 24 hours, however, the oxygen uptake rate for the oil-amended sediments surpassed the enhanced rates observed for the glucose-amended sediments (Figures 19 and 20). As before, similar increases in respiratory activity were observed for all samples.

Temperature coefficients were calculated for both unamended and glucose-supplemented samples by using data from Tables 59 and 60 and Figure 21. The Q_{10} for unsupplemented and supplemented sediments was 2.405 and 2.636, respectively.

DISCUSSION

The dominant distinguishing characteristics of the glacial silt intertidal ecosystem studied at Port Valdez, Alaska, as compared to sediment intertidal systems studied by others, appear to be comparatively small mean grain size of the sediment particles, the lack of significant wave action, or of significant input of organic material derived from external sources.

Although the relatively small grain size of 4 to 16 µ provides ample surface area for establishment of bacterial microcolonies (Dale, 1974)[89], their close packing greatly reduces the size of the interstitial spaces through which nutrients might be delivered to the sediment-bound bacteria. While the total surface area on the particles might be larger than in sand systems, the small physical size precludes the growth of more than a few bacterial cells on any one sediment grain. The smaller interstitial spaces would be expected to clog rapidly, providing little or no opportunity for migration of microorganisms or for the movement of nutrients through the sediment. Clearly, the bulk of any organic material that might be

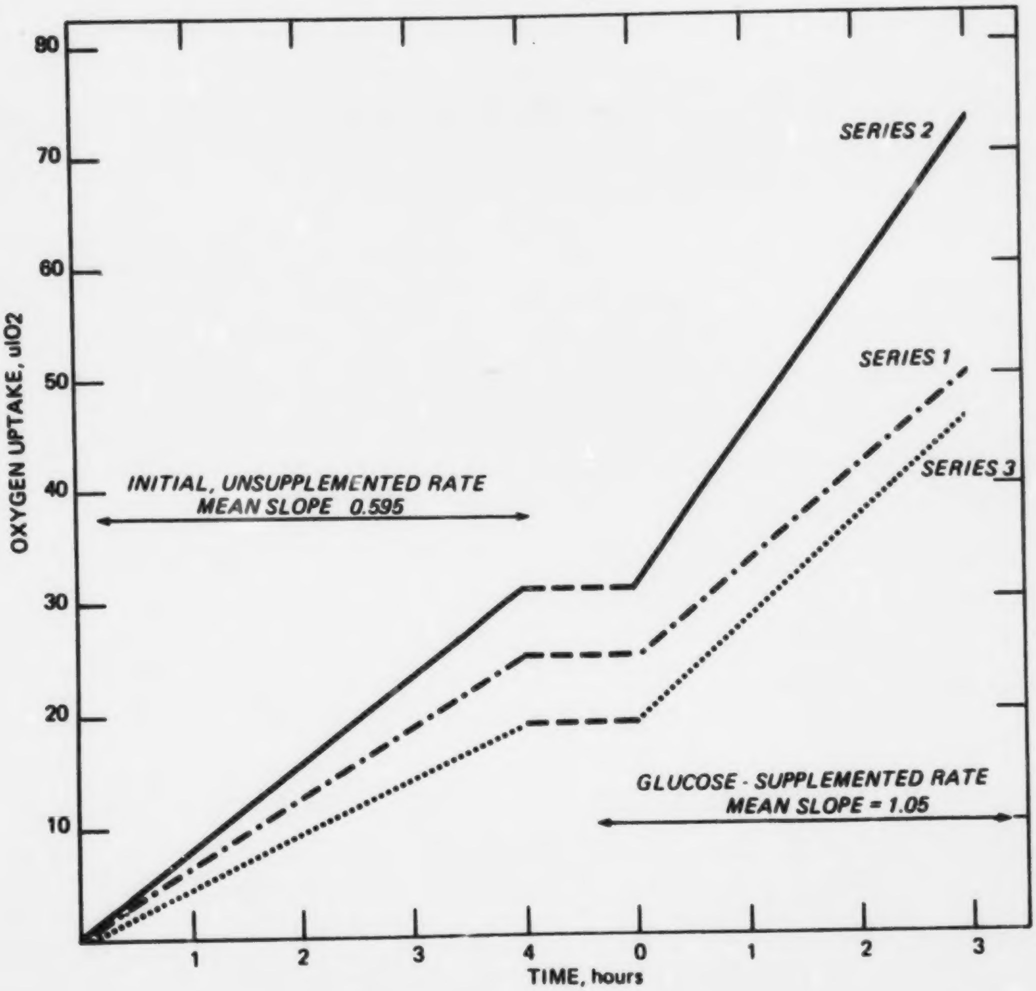

Figure 19. Effect of added glucose on oxygen uptake by control sediment. Conditions as in Table 59.

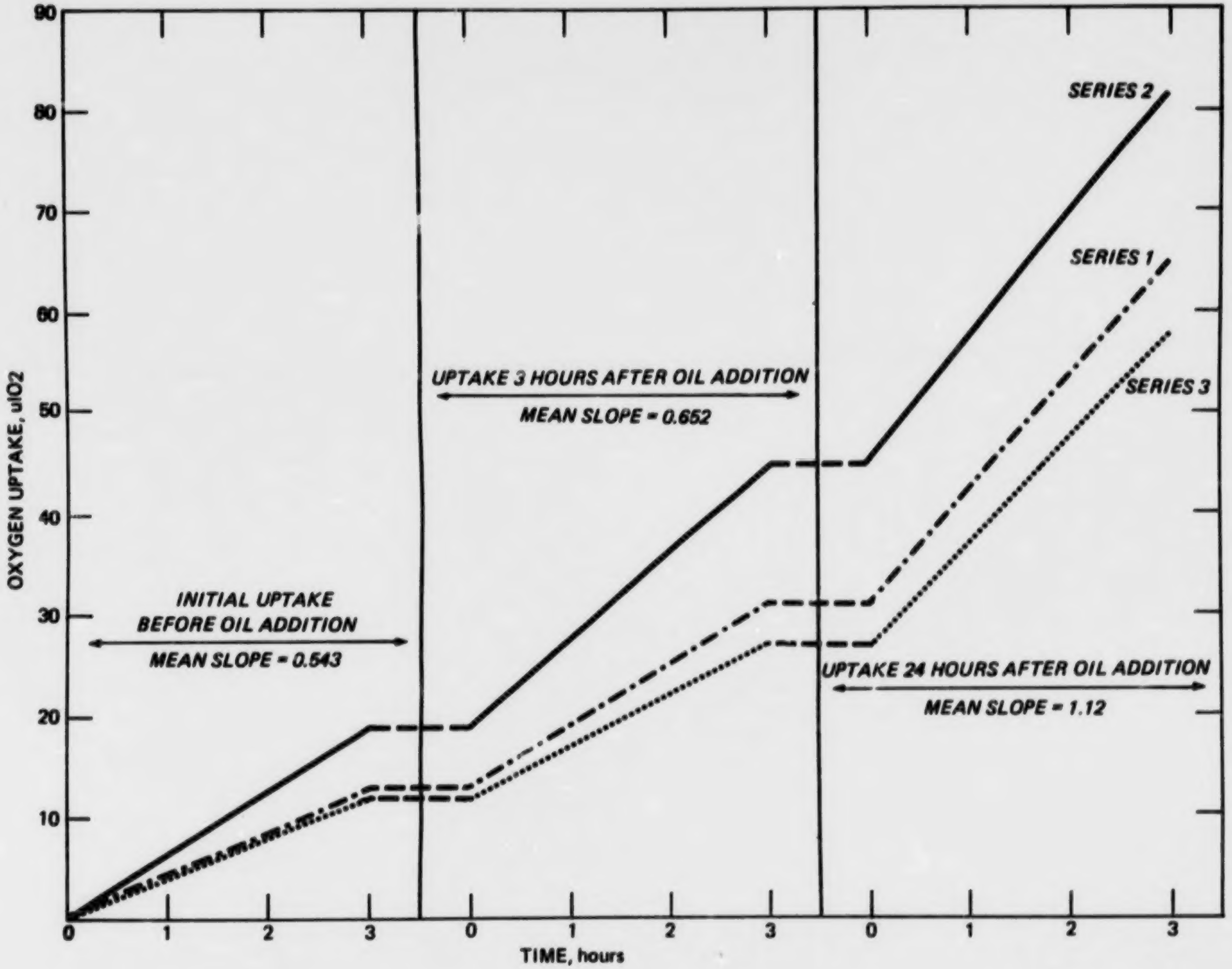

Figure 20. Effect of added oil on oxygen uptake by control sediment. Conditions as in Table 60.

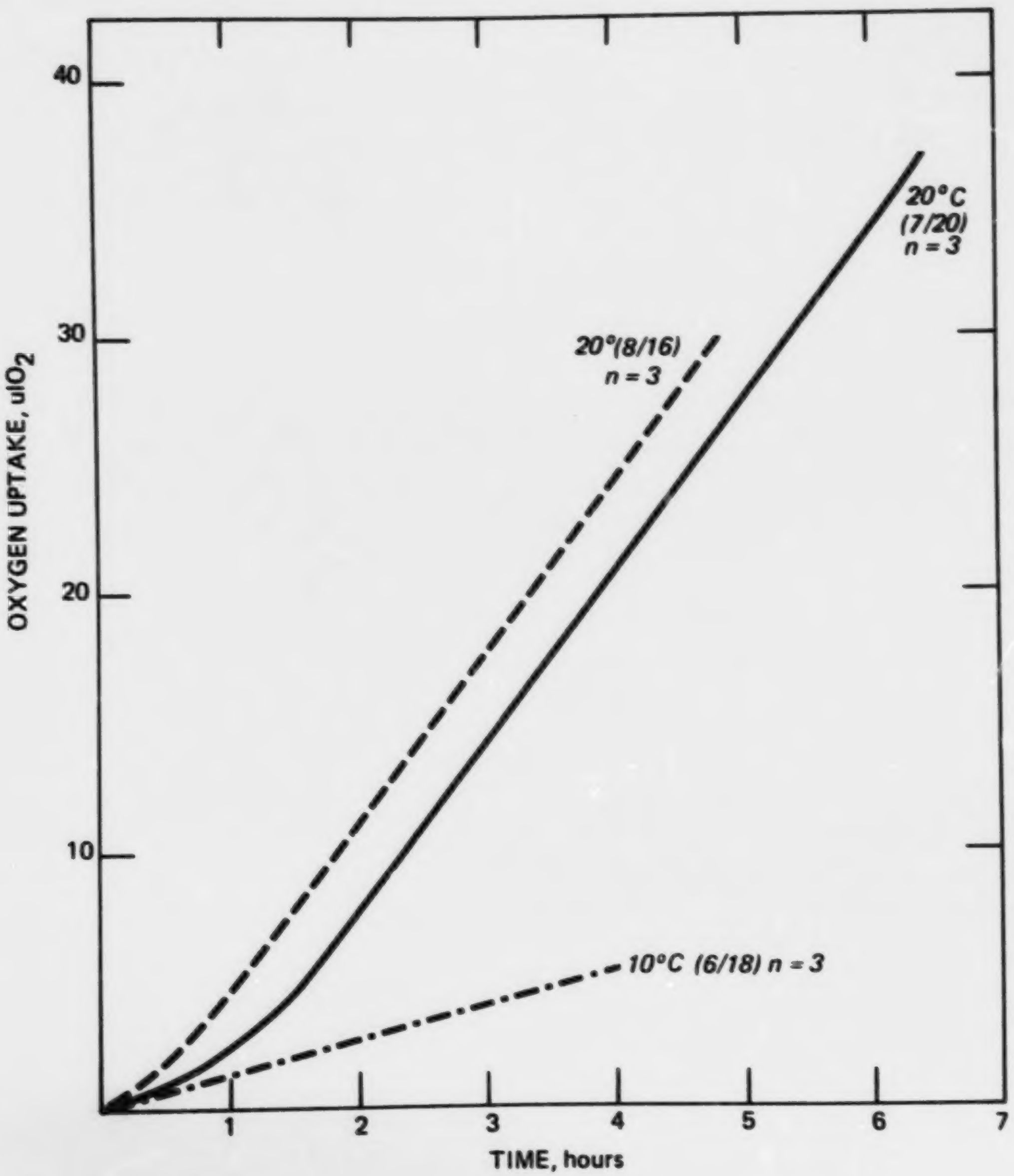

Figure 21. Effect of reaction temperature on oxygen uptake by unsupplemented sediment samples. All samples from control sites.

deposited on the sediment, whether soluble or particulate, will be removed at the surface, probably by tidal action. The low mean temperatures and expected reduced metabolic activity ($Q_{10-20°} = 2.5$), fairly rapid tidal surface flushing, almost continuous surface washing by precipitation, and the compactness of the sediment itself preclude rapid digestion of organic material at the surface by bacteria or extensive movement of dissolved organics into the sediment for retention and slower digestion. The relatively gentle tidal changes (as shown by the stability of the test rings: See Section X) would also preclude physical burial of detritus. It is apparent that no significant enrichment of the bacterial population occurs or, if it does, it is removed from the surface by ebb tide along with any deposited organic material.

The low bacterial counts, the failure of field populations to respond to *in situ* addition of organics, and the low number of anaerobic sulfur reducers support the conclusion that the sediments at Valdez intertidal zones do not support even a modest microbial biomass, and would not respond to surface applied organics, such as would occur following an oil spill. On the other hand, the *in vitro* experiments reported here suggest that the bacterial population will respond to added organic material if the nutrients can be delivered to the organisms by careful mixing with sediment.

The increased uptake of oxygen and the succession of changes in microaquaria support the hypothesis that this ecosystem is organically poor, but that it will respond when organic nutrients are made available to the microorganisms by mixing either glucose or oil with the sediment. The microaquaria technique of Fenchel (1969)[86] demonstrated that a relatively normal succession of bacterial types, with expected modification due to the paucity of photosynthetic and chemoautotrophic forms, will occur under appropriate environmental conditions.

The initial blackening of the medium in the microaquaria is due to the production of hydrogen sulfide from organic sources by the large proportion of the population that are able to digest sulfur containing amino acids. As the chemoautotrophic and small numbers of photosynthetic bacteria develop, the hydrogen sulfide is oxidized, resulting in a lightening of the medium, and, as the redox discontinuity point moves down through the liquid phase, the chemoautotrophic bacterial growth band similarly moves, resulting in eventual removal of hydrogen sulfide from the entire liquid phase. The modest growth of pigmented organisms in the sediment at the bottom of the liquid phase represents response of the Rhodospirillaceae (Athiorhodaceae) to the organic components of the medium and the anerobic conditions that exist below the redox discontinuity level. In contrast, the failure to detect even modest numbers of sulfide-oxidizing bacteria (chemoautotrophic or photoautotrophic) is consistent with the reported low sulfide content and aerobic conditions of the sediment.

It should be noted, however, that the procedures used in this report do not measure dynamics in the bacterial populations, but, instead, measure the standing crops at any given time. The plate count data and the respirometry data measure only the numbers or activity of the bacterial population, but give no indication of the turnover of the biomass (see Strickland, 1971[104], and Gray and Williams, 1971[105], for a discussion of this relationship) or of changes in the proportional distribution of certain species within the population. It is not unreasonable to expect changes in the species represented and/or increased turnover due to grazing without noting changes in the size of the standing crop. There are, indeed, some indications that this might be the case. For example, the percentage of bacterial colonies able to produce hydrogen sulfide from organic sources was observed to change seasonally, from a low of 34% from the 18 June sample to a high of 94% from the 5 August sample (both after 14 days incubation). Furthermore, the application of the oil resulted in a slight reduction in the sulfide producers, when compared to the control sediments (Table 57). However, during these same sampling periods no change was observed in the total heterotrophic bacterial counts (Table 56). Finally, a statistically significant increase in two species of harpacticoid copepods (*Halectinosoma gothiceps* and *Heterolaophonte* sp.) in sediments taken from oiled sites has been demonstrated (Section X). Harpacticoid copepods have been described as bacterial feeders, and may be cropping bacteria at the same rate as they are produced.

SECTION X

EFFECT OF PRUDHOE BAY CRUDE OIL ON THREE SPECIES OF SEDIMENT-DWELLING HARPACTICOID COPEPODS ON ISLAND FLATS, PORT VALDEZ

The effect of oil on sediment-dwelling fauna is little understood, and field-generated experimental data on the effects of petroleum products on meiofauna is non-existent in the published literature. Several authors have quantitated oil concentrations in sediments, and have noted their persistence (Scarratt and Zitko, 1972[106]; Blumer and Sass, 1972[107]; Tissier and Oudin, 1973[108]; Evans and Rice, 1974[109] for review). A number of studies have been concerned with the ability of crude oil to supply oxidizable soluble organic material to bacterial populations in marine sand ecosystems (see Section IX for review), but none of these studies has examined the interrelationships with meiofauna in these systems. All previous studies reported have been accomplished on relatively coarse sediment systems which were pervious to oil residues. The study reported here is unique in the fact that the sediment of the experimental area is of recent glacial origin with a mean particle size of 4 to 16 microns, contains little natural organic material, and potentially has a low capacity to sequester hydrocarbons (see Section IV and VIII for discussion on the relationship of oil to sediment parameters on Island Flats). The meiofaunal organisms in this system are restricted primarily to the upper three centimeters (see Section VI for a description of the meiofauna of Island Flats). Most coarse sediment systems of the type alluded to above would be vulnerable to oil spills layering on the surface, but the geological, bacterial and hydrocarbon studies reported in Section VIII, IX, and X suggest that small sediment organisms may not be significantly affected by oil additions to the sediment surface in Port Valdez.

It was the purpose of the field experiments described here to determine the effect of Prudhoe Bay crude oil on three species of harpacticoid copepods (*Harpacticus uniremis, Halectinosoma gothiceps,* and *Heterolaophonte* sp.) living in the sediment on a mudflat in Port Valdez (see Section VI for baseline data on these species).

GENERAL MATERIALS AND METHODS

All procedures were accomplished during the summer months of 1974 on an intertidal (0.0 m) sampling site on Island Flats, Port Valdez (Section IV, Figure 1). All experiments were carried out in conjunction with a geological, microbiological, meiofaunal, and hydrocarbon sampling program in the same area. A complete description of the study site is found in Section IV.

Two types of experiments were performed, and are described separately below.

EXPERIMENT 1 - *A test of the immediate effect of three concentrations of Prudhoe Bay crude oil on the density of three species of sediment-dwelling harpacticoid copepods.*

Experimental Procedure and Sampling

One hundred and twenty (120) glass rings each 3 1/2 cm high with a radius of 7.25 cm were placed on the tidal flat at the 0.0 m tidal level and pressed gently into the mud. Figures 22 and 23 illustrates the arrangements of the rings. At low tide on 19 and 20 June, 1974 the rings were filled to a height of 3 cm with sea water, and 0.25 ml (500 ppm) of Prudhoe Bay crude oil added to rings 31 through 60, 0.50 ml (1000 ppm) to rings 61 through 90, and 1.0 ml (2000 ppm) to 91 through 120. A volumetric pipette was used for all oil additions. Rings 1 through 30 served as controls. The oil formed a slick which floated on the sea water in each ring. The water percolated through the sediment and the oil slick spread over the sediment surface as the water drained from the rings.

On the following tide series, 20 cores were taken from rings 1 through 6, 31 through 36, 61 through 66, and 91 through 120. The cores were collected with a 2 cm glass coring tube. The first centimeter of the core was removed, and immediately preserved with 10% buffered formalin. The remaining rings were again subjected to additional oil treatments as described above. This procedure was followed throughout the experiment. The dates for oil additions and collections of samples are included in Table 61. All preserved*

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*Note: Continuation of text on page 211.

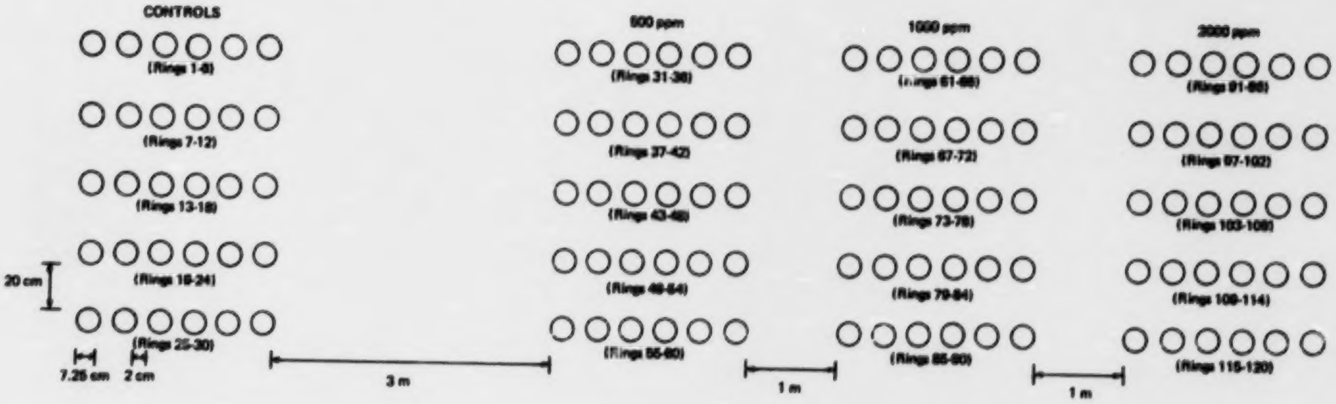

Figure 22. The experimental arrangement of glass rings used to test the effect of three concentrations of Prudhoe Bay crude oil on three species of harpacticoid copepods at Island Flats.

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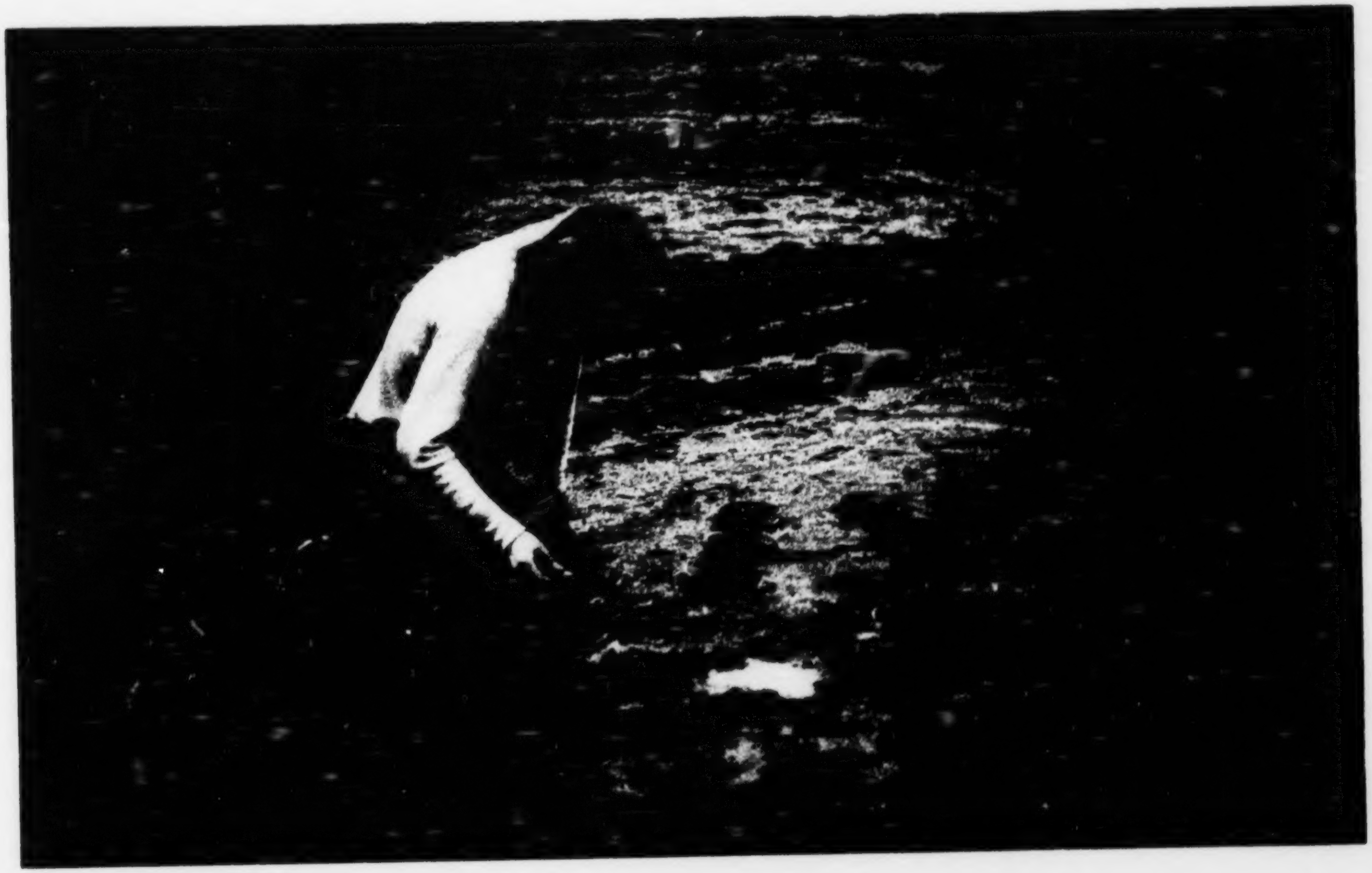

Figure 23. View of glass rings in place during oiling procedures used to test the effect of three concentrations of Prudhoe Bay crude oil on three species of harpacticoid copepods at Island Flats.

TABLE 61

PRUDHOE BAY CRUDE OIL ADDITIONS AND COLLECTIONS

SEDIMENT, BACTERIAL, MEIOFAUNAL AND OIL STUDIES, SUMMER - 1974.

C = CONTROL CORE, O = OIL CORE

Ring No.[a]	Dates Oiled	Concentration of oil (ppm)	Core No. for meiofauna; other samples	Date Collected
1	June[b]	0 (control)	C 1-20	July 3
2	June[b]	0 (control)	C 21-40	July 4
3	June[b]	0 (control)	C 41-60	July 4
4	June[b]	0 (control)	C 61-80	July 4
5	June[b]	0 (control)	Sed. Sam.	July 4
6	June[b]	0 (control)	Bact. Cores	July 3
31	June[b]	500	O 1-20	July 3
32	June[b]	500	O 21-40	July 3
33	June[b]	500	O 41-60	July 3
34	June[b]	500	O 61-80	July 3
35	June[b]	500	Sed. Sam.	July 3
36	June[b]	500	Bact. Cores	July 3
61	June[b]	1000	O 81-100	July 4
62	June[b]	1000	O 101-120	July 4

TABLE 61 (continued)

PRUDHOE BAY CRUDE OIL ADDITIONS AND COLLECTIONS

Ring No.[a]	Dates Oiled	Concentration of oil (ppm)	Core No. for meiofauna; other samples	Date Collected
63	June[b]	1000	O 121-140	July 4
64	June[b]	1000	O 141-160	July 4
65	June[b]	1000	Sed. Sam.	July 4
66	June[b]	1000	No Sam. Taken	
91	June[b]	2000	O 161-180	July 5
92	June[b]	2000	O 181-200	July 5
93	June[b]	2000	O 201-220	July 5
94	June[b]	2000	O 221-240	July 5
95	June[b]	2000	Sed. Sam.	July 5
96	June[b]	2000	Bact. Sam.	July 3
7	June[c] July	0 (control)	C 81-100	July 18
8	June[c] July	0 (control)	C 101-120	July 18
9	June[c] July	0 (control)	C 121-140	July 18
10	June[c] July	0 (control)	C 141-160	July 18

TABLE 61 (continued)

PRUDHOE BAY CRUDE OIL ADDITIONS AND COLLECTIONS

Ring No.[a]	Dates Oiled	Concentration of oil (ppm)	Core No. for meiofauna; other samples	Date Collected
11	June[c] July	0 (control)	Sed. Sam.	July 18
12	June[c] July	0 (control)	Bact. Sam.	July 20
37	June[c] July	500	0 241-260	July 19
38	June[c] July	500	0 261-280	July 19
39	June[c] July	500	0 281-300	July 19
40	June[c] July	500	0 301-320	July 19
41	June[c] July	500	Sed. Sam.	July 19
42	June[c] July	500	Bact. Sam.	July 20
67	June[c] July	1000	0 321-340	July 20
68	June[c] July	1000	0 341-360	July 20
69	June[c] July	1000	0 361-380	July 20
70	June[c] July	1000	0 381-400	July 20
71	June[c] July	1000	Sed. Sam.	July 20
72	June[c] July	1000	No Sam. Taken	

TABLE 61 (continued)

PRUDHOE BAY CRUDE OIL ADDITIONS AND COLLECTIONS

Ring No.[a]	Dates Oiled	Concentration of oil (ppm)	Core No. for meiofauna; other samples	Date Collected
97	June[c] July	2000	O 401-420	July 20
98	June[c] July	2000	O 421-440	July 20
99	June[c] July	2000	O 441-460	July 20
100	June[c] July	2000	O 461-480	July 20
101	June[c] July	2000	Sed. Sam.	July 20
102	June[c] July	2000	Bact. Sam.	July 20
13	June[d] July	0 (control)	C 161-180	Aug. 2
14	June[d] July	0 (control)	C 181-200	Aug. 2
15	June[d] July	0 (control)	C 201-220	Aug. 2
16	June[d] July	0 (control)	C 221-240	Aug. 2
17	June[d] July	0 (control)	Sed. Sam.	Aug. 2
18	June[d] July	0 (control)	Bact. Sam.	Aug. 5
43	June[d] July	500	O 481-500	Aug. 5
44	June[d] July	500	O 501-520	Aug. 5

TABLE 61 (continued)

PRUDHOE BAY CRUDE OIL ADDITIONS AND COLLECTIONS

Ring No.[a]	Dates Oiled	Concentration of oil (ppm)	Core No. for meiofauna; other samples	Date Collected
45	June[d] July	500	O 521-540	Aug. 5
46	June[d] July	500	O 541-560	Aug. 5
47	June[d] July	500	Sed. Sam.	Aug. 5
48	June[d] July	500	Bact. Sam.	Aug. 5
73	June[d] July	1000	O 561-580	Aug. 5
74	June[d] July	1000	O 581-600	Aug. 5
75	June[d] July	1000	O 601-620	Aug. 5
76	June[d] July	1000	O 621-640	Aug. 5
77	June[d] July	1000	Sed. Sam.	Aug. 5
78	June[d] July	1000	No Sam. Taken	
103	June[d] July	2000	O 641-660	Aug. 5
104	June[d] July	2000	O 661-680	Aug. 5
105	June[d] July	2000	O 681-700	Aug. 5
106	June[d] July	2000	O 701-720	Aug. 5

TABLE 61 (continued)

PRUDHOE BAY CRUDE OIL ADDITIONS AND COLLECTIONS

Ring No.[a]	Dates Oiled	Concentration of oil (ppm)	Core No. for meiofauna; other samples	Date Collected
107	June[d] July	2000	Sed. Sam.	Aug. 5
108	June[d] July	2000	Bact. Sam.	Aug. 5
19	June[e] July August	0 (control)	C 241-260	Aug. 16
20	June[e] July August	0 (control)	C 261-280	Aug. 16
21	June[e] July August	0 (control)	C 281-300	Aug. 16
22	June[e] July August	0 (control)	C 301-320	Aug. 16
23	June[e] July August	0 (control)	Sed. Sam.	Aug. 16
24	June[e] July August	0 (control)	Bact. Sam.	Aug. 26
49	June[e] July August	500	O 721-740	Aug. 26
50	June[e] July August	500	O 741-760	Aug. 26
51	June[e] July August	500	O 761-780	Aug. 26

TABLE 61 (continued)

PRUDHOE BAY CRUDE OIL ADDITIONS AND COLLECTIONS

Ring No.[a]	Dates Oiled	Concentration of oil (ppm)	Core No. for meiofauna; other samples	Date Collected
52	June[e] July August	500	0 781-800	Aug. 26
53	June[e] July August	500	Sed. Sam.	Aug. 26
54	June[e] July August	500	Bact. Sam.	Aug. 26
79	June[e] July August	1000	0 801-820	Aug. 26
80	June[e] July August	1000	0 821-840	Aug. 26
81	June[e] July August	1000	0 841-860	Aug. 26
82	June[e] July August	1000	0 861-0880	Aug. 26
83	June[e] July August	1000	sed. sam.	Aug. 26
84	June[e] July August	1000	No sam. taken	
109	June[e] July August	2000	0 881-900	Aug. 26
110	June[e] July August	2000	0 901-920	Aug. 26

TABLE 61 (continued)

PRUDHOE BAY CRUDE OIL ADDITIONS AND COLLECTIONS

Ring No.[a]	Dates Oiled	Concentration of oil (ppm)	Core No. for meiofauna; other samples	Date Collected
111	June[e] July August	2000	O 921-940	Aug. 26
112	June[e] July August	2000	O 941-960	Aug. 26
113	June[e] July August	2000	Sed. Sam.	Aug. 26
114	June[e] July August	2000	Bact. Sam.	Aug. 26
25	June[e] July August	0 (control)	C 321-340	Sept. 15
26	June[e] July August	0 (control)	C 341-360	Sept. 15
27	June[e] July August	0 (control)	C 361-380	Sept. 15
28	June[e] July August	0 (control)	C 381-400	Sept. 15
29	June[e] July August	0 (control)	Sed. Sam.	Sept. 15
30	June[e] July August	0 (control)	Bact. Sam.	Sept. 15
55	June[e] July August	500	O 961-980	Sept. 15

TABLE 61 (continued)
PRUDHOE BAY CRUDE OIL ADDITIONS AND COLLECTIONS

Ring No.[a]	Dates Oiled	Concentration of oil (ppm)	Core No. for meiofauna; other samples	Date Collected
56	June[e] July August	500	O 981-1000	Sept. 15
57	June[e] July August	500	O 1000-1020	Sept. 15
58	June[e] July August	500	O 1021-1040	Sept. 15
59	June[e] July August	500	Sed. Sam.	Sept. 15
60	June[e] July August	500	Oil-Sed. Sam.	Sept. 15
85	June[e] July August	1000	O 1041-1060	Sept. 15
86	June[e] July August	1000	O 1061-1080	Sept. 15
87	June[e] July August	1000	O 1081-1100	Sept. 15
88	June[e] July August	1000	O 1101-1120	Sept. 15
89	June[e] July August	1000	Sed. Sam.	Sept. 15
90	June[e] July August	1000	Oil-Sed. Sam.	Sept. 15

TABLE 61 (continued)

PRUDHOE BAY CRUDE OIL ADDITIONS AND COLLECTIONS

Ring No.[a]	Dates Oiled	Concentration of oil (ppm)	Core No. for meiofauna; other samples	Date Collected
115	June[f] July August	2000	O 1121-1140	Sept. 15
116	June[f] July August	2000	O 1141-1160	Sept. 15
117	June[f] July August	2000	O 1161-1180	Sept. 15
118	June[f] July August	2000	O 1181-1200	Sept. 15
119	June[f] July August	2000	Sed. Sam.	Sept. 15
120	June[f] July August	200	Oil-Sed. Sam.	Sept. 15

[a] See Methods Section for use of rings in experimental procedures.

[b] June 19 and 20, 1974.

[c] June 19, 20, and July 3, and 4, 1974.

[d] June 19, 20, and July 3, 4, 20, and 21, 1974.

[e] June 19, 20, and July 3, 4, 20, 21, and August 2, and 3, 1974.

[f] June 19, 20, and July 3, 4, 20, 21, and August 2, 3, 16 and 17, 1974.

samples were taken to the laboratory at the Marine Sorting Center (University of Alaska), Rose Bengal was added to each sample container, the material washed through 64 micron-mesh Nitex screen, and examined with a dissection microscope. Three copepod species (*Harpacticus uniremis, Halectinosoma gothiceps,* and *Heterolaophonte* sp.) were then counted under the microscope.

A one-way analysis of variance (Olivetti Underwood Programa 101, program 6.10) was used to examine the copepod population in 15 cores (three rows of five cores, each row 10 m apart) taken at the study site on 2 June 1973 and 11 November 1973 prior to the oil experiment. This same analysis was also used to compare the numbers of each copepod species on the test rings and the control rings.

Concurrent with the copepod collections, sediment chemistry and bacterial populations were monitored from sediments of separate rings placed adjacent to the meiofaunal test rings (see Section VIII and IX). Analysis of sediments for hydrocarbons was made at the beginning and the end of the experiment (Section XI).

Results

The one-way analysis of variance performed on the three rows of five cores prior to the oil-addition experiments showed that no significant difference ($\alpha = .01$) could be detected between the numbers of each of three copepod species, *Harpacticus uniremis, Halectinosoma gothiceps,* and *Heterolaophonte* sp. found in any of the 15 cores. Therefore, the distribution of the three species on the study site was considered random.

As water drained from the rings with contained oil, the slick settled to the sediment. Multicolors were visible on the bottom; black aggregates of oil settled in low places with some attaching to the sides of the glass rings. The oil was visible at the sediment surface for two to three days after oil addition when observed at low tide. The color of the substratum returned to a normal gray appearance after this period of time. This situation was true for all cumulative additions of oil on the rings at all concentrations.

At the 500 ppm oil concentration, *Harpacticus uniremis* was not adversely affected by the addition (Table 62; Figure 24). In all cases there was either no significant difference ($\alpha = .01$) in numbers of copepods in the control and oil plots or else there was a greater number of copepods in the oiled areas. *Halectinosoma gothiceps* was likewise not adversely affected by the addition of oil at 500 ppm. Throughout the experiment there was either no significant differences ($\alpha = .01$) in the number of individuals in the controls and the oiled rings or there were more individuals in the oiled plots (Table 62; Figure 25). There were significantly ($\alpha = .01$) more copepods present in one oiled ring on July 4, one oiled ring on July 18, and two oiled rings on August 2. The numbers of *Heterolaophonte* sp. in the control and test rings generally showed no significant difference ($\alpha = .01$) following oil additions at 500 ppm. In the July 18 collection more ($\alpha = .01$) animals appear in a control ring (Table 62; Figure 26).

At 1000 ppm the numbers of *Harpacticus uniremis* were generally unaffected by the addition of oil (Table 63; Figure 24). When significant differences ($\alpha = .01$) did occur, there was an increased number of copepods in one of four oiled rings (July 18 and September 15) and once in one of the control rings (August 2).

Halectinosoma gothiceps exhibited the same general pattern of response at 1000 ppm as it did at 500 ppm crude oil addition. There was either no difference in number of animals in the controls and the oiled plots or there were more copepods in the oiled plots. There were significantly ($\alpha = .01$) more copepods present in two oiled rings on July 18, four oiled rings on August 2, and two on August 16. In only one control ring (July 4) were theresignificantly more copepods present than in the oiled rings (Table 63; Figure 25). The response of *Heterolaophonte* sp. to 1000 ppm of crude oil was somewhat similar to that found for *H. gothiceps* (Table 63; Figures 25 and 26).

In the test area subjected to 2000 ppm of crude oil, *Harpacticus uniremis* showed no significant ($\alpha = .01$) difference in numbers in the test rings and the controls in July. There were significantly more *H. uniremis* in[*]

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[*]Note: Continuation of text on page 225.

TABLE 62

RESULTS OF OIL ADDITION AT 500 ppm ON THREE SPECIES OF INTERTIDAL HARPACTICOID COPEPODS FROM PORT VALDEZ, ALASKA, SUMMER - 1974

Cores with prefix O are experimental cores subjected to oil addition; those with prefix of C are unoiled Prudhoe Bay crude oil controls. See Methods Section for oil amendment and statistical procedures.

			Harpacticus uniremis (Type 1)	
Dates of[a] oil addition to experimental areas	Dates of collection	Cores with no significant difference between number of copepods ($\alpha = .01$)	Cores with significantly more copepods in oiled sample ($\alpha = .01$)	Cores with significantly more copepods in unoiled sample ($\alpha = .01$)
June 19 June 20	July 3-5	O 1-20 (C 1-20)[b] O 21-40 (C 21-40) O 61-80 (C 61-80)	O 41-60 (C 41-60)	None
June 19 June 20 July 3 July 4	July 18	O 241-260 (C 81-100) O 261-280 (C 101-120) O 301-320 (C 141-160)	O 281-300 (C 121-140)	None
June 19 June 20 July 3 July 4 July 20 July 21	Aug. 2	O 481-500 (C 161-180) O 501-520 (C 181-200) O 521-540 (C 201-220) O 541-560 (C 221-240)	None	None
June 19 June 20 July 3 July 4 July 20 July 21 Aug. 2 Aug. 3	Aug. 16	O 721-740 (C 241-260) O 741-760 (C 261-280) O 761-780 (C 281-300) O 781-800 (C 301-320)	None	None
June 19 June 20 July 3 July 4 July 20 July 21 Aug. 2 Aug. 3 Aug. 16 Aug. 17	Sept. 15	O 961-980 (C 321-340)	O 981-1000 (C 341-360) O 1001-1020 (C 361-380) O 1021-1040 (C 381-400)	None

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[a] Multiple dates (at each oil-addition period) represent cumulative additions of oil to rings on the dates listed.

[b] Control cores in parentheses represent data used in the statistical tests for significance (one-way analysis of variance).

TABLE 62 (continued)

RESULTS OF OIL ADDITION AT 500 ppm ON THREE SPECIES OF INTERTIDAL HARPACTICOID COPEPODS

			Halectinosoma gothiceps (Type 4)	
Dates of[a] oil addition to experimental areas	Dates of collection	Cores with no significant difference between number of copepods (α = .01)	Cores with significantly more copepods in oiled sample (α = .01)	Cores with significantly more copepods in unoiled sample (α = .01)
June 19 June 20	July 3-5	0 1-20 (C 1-20)[b] 0 21-40 (C 21-40) 0 41-60 (C 41-60)	0 61-80 (C 61-80)	None
June 19 June 20 July 3 July 4	July 18	0 241-260 (C 81-100) 0 261-280 (C 101-120) 0 281-300 (C 121-140)	0 301-320 (C 141-160)	None
June 19 June 20 July 3 July 4 July 20 July 21	Aug. 2	0 481-500 (C 161-180) 0 501-520 (C 181-200)	0 521-540 (C 201-220) 0 541-560 (C 221-240)	None
June 19 June 20 July 3 July 4 July 20 July 21 Aug. 2 Aug. 3	Aug. 16	0 721-740 (C 241-260) 0 741-760 (C 261-280) 0 761-780 (C 281-300) 0 781-800 (C 301-320)	None	None
June 19 June 20 July 3 July 4 July 20 July 21 Aug. 2 Aug. 3 Aug. 16 Aug. 17	Sept. 15	0 961-980 (C 321-340) 0 981-1000 (C 341-360) 0 1001-1020 (C 361-380) 0 1021-1040 (C 381-400)	None	None

[a] Multiple dates (at each oil-addition period) represent cumulative additions of oil to rings on the dates listed.

[b] Control cores in parentheses represent data used in the statistical tests for significance (one-way analysis of variance).

TABLE 62 (continued)

RESULTS OF OIL ADDITION AT 500 ppm ON THREE SPECIES OF INTERTIDAL HARPACTICOID COPEPODS

			Heterolaophonte sp. (Type 10)	
Dates of[a] oil addition to experimental areas	Dates of collection	Cores with no significant difference between number of copepods (α = .01)	Cores with significantly more copepods in oiled sample (α = .01)	Cores with significantly more copepods in unoiled sample (α = .01)
June 19 June 20	July 3-5	O 1-20 (C 1-20)[b] O 21-40 (C 21-40) O 41-60 (C 41-60) O 61-80 (C 61-80)	None	None
June 19 June 20 July 3 July 4	July 18	O 241-260 (C 81-100) O 261-280 (C 101-120) O 301-320 (C 141-160)	None	O 281-300 (C 121-140)
June 19 June 20 July 3 July 4 July 20 July 21	Aug. 2	O 481-500 (C 161-180) O 501-520 (C 181-200) O 521-540 (C 201-220) O 541-560 (C 221-240)	None	None
June 19 June 20 July 3 July 20 July 21 Aug. 2 Aug. 3	Aug. 16	O 721-740 (C 241-260) O 741-760 (C 261-280) O 761-780 (C 281-300) O 781-800 (C 301-320)	None	None
June 19 June 20 July 3 July 4 July 20 July 21 Aug. 2 Aug. 3 Aug. 16 Aug. 17	Sept. 15	None	None	None

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[a] Multiple dates (at each oil-addition period) represent cumulative additions of oil to rings on the dates listed.

[b] Control cores in parentheses represent data used in the statistical tests for significance (one-way analysis of variance).

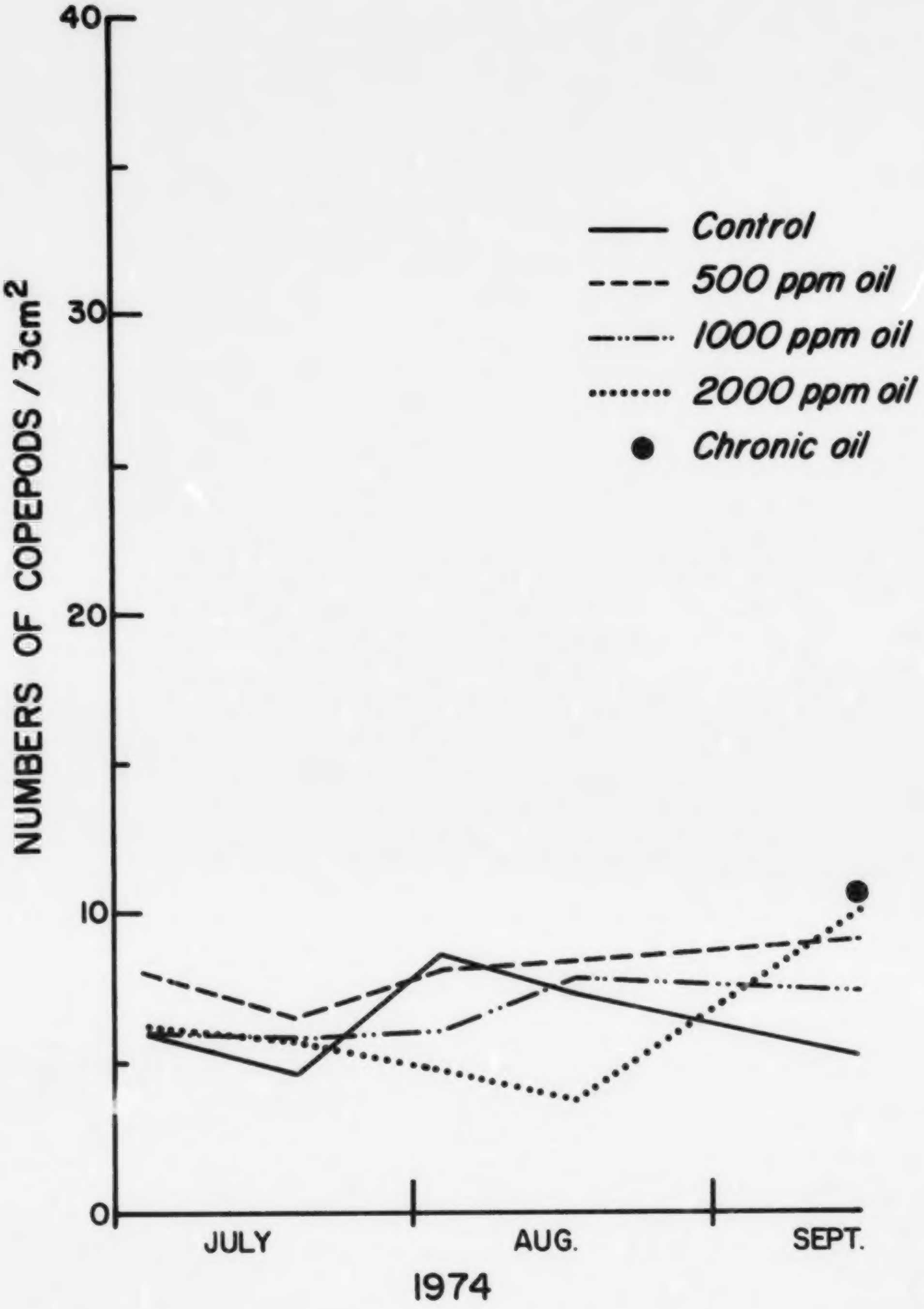

Figure 24. The number of *Harpacticus uniremis* during an oil-addition experiment on Island Flats, Port Valdez. See methods for oil ammendment and other procedures used in experiment.

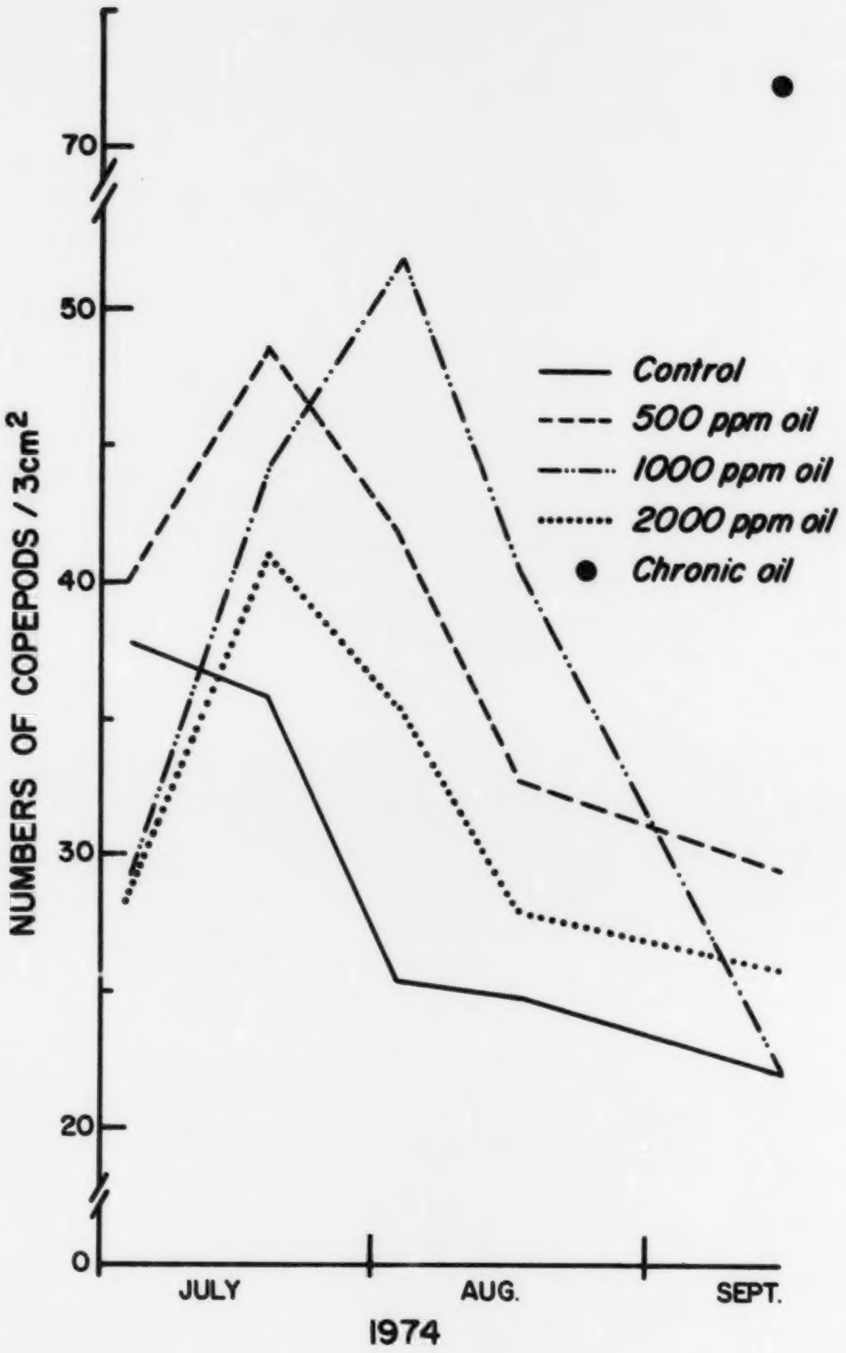

Figure 25. The number of *Halectinosoma gothiceps* during an oil-addition experiment on Island Flats, Port Valdez. See methods for oil ammendment and other procedures used in experiment.

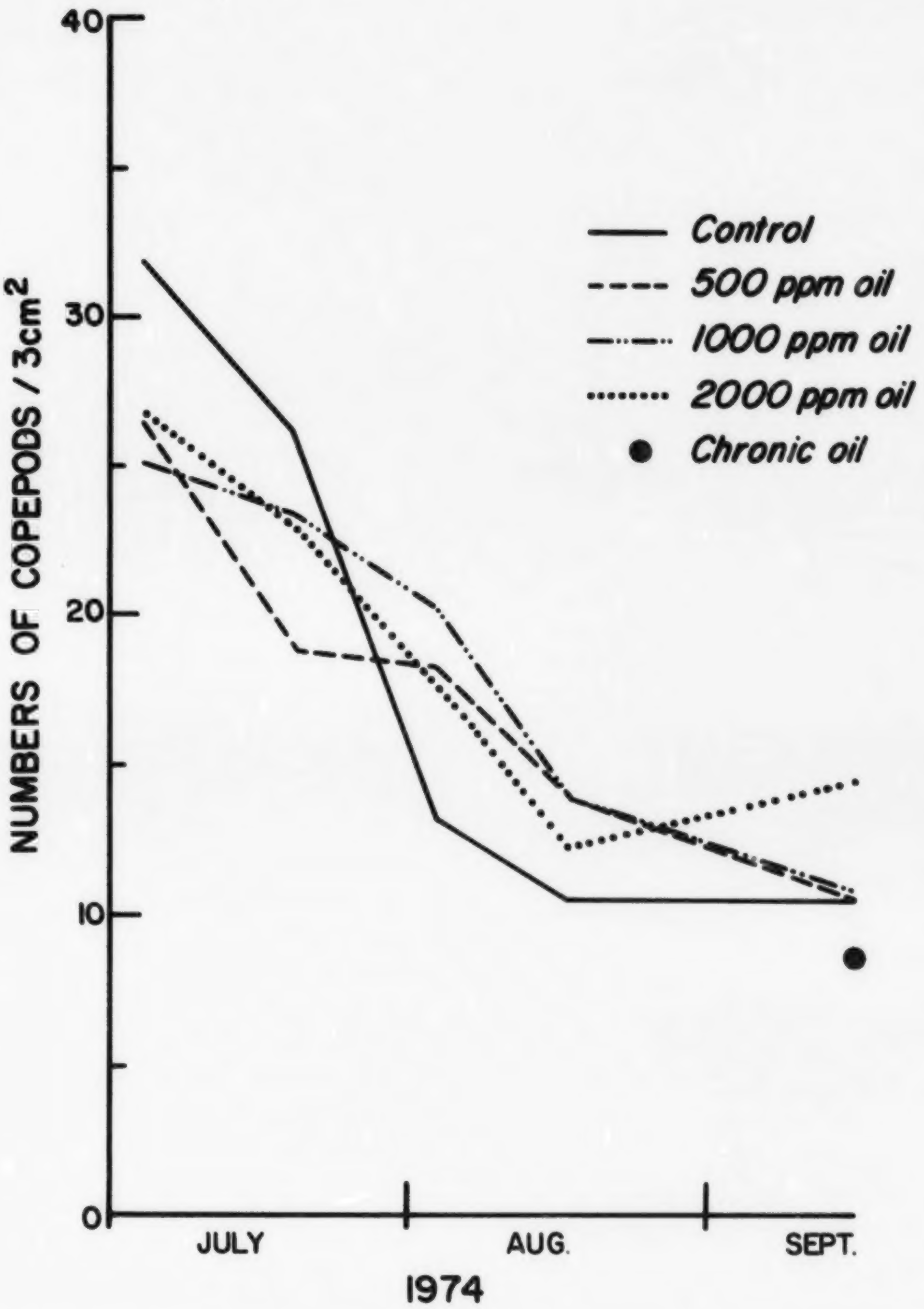

Figure 26. The number of *Heterolaophonte* sp.. during an oil-addition experiment on Island Flats, Port Valdez. See methods for oil ammendment and other procedures used in experiment.

TABLE 63

RESULTS OF OIL ADDITION AT 1000 ppm ON THREE SPECIES OF INTERTIDAL HARPACTICOID COPEPODS FROM PORT VALDEZ, ALASKA, SUMMER - 1974

Cores with prefix O are experimental cores subjected to oil addition; those with prefix of C are unoiled Prudhoe Bay crude oil controls. See Methods Section for oil amendment and statistical procedures.

		Harpacticus uniremis (Type 1)		
Dates of[a] oil addition to experimental areas	Dates of collection	Cores with no significant difference between number of copepods (α = .01)	Cores with significantly more copepods in oiled sample (α = .01)	Cores with significantly more copepods in unoiled sample (α = .01)
June 19 June 20	July 3-5	O 81-100 (C 1-20)[b] O 101-120 (C 21-40) O 121-140 (C 41-60) O 141-160 (C 61-80)	None	None
June 19 June 20 July 3 July 4	July 18	O 321-340 (C 81-100) O 341-360 (C 101-120) O 381-400 (C 141-160)	O 361-380 (C 121-140)	None
June 19 June 20 July 3 July 4 July 20 July 21	Aug. 2	O 581-600 (C 181-200) O 601-620 (C 201-220) O 621-640 (C 221-240)	None	O 561-580 (C 161-180)
June 19 June 20 July 3 July 4 July 20 July 21 Aug. 2 Aug. 3	Aug. 16	O 801-820 (C 241-260) O 821-840 (C 261-280) O 841-860 (C 281-300) O 861-880 (C 301-320)	None	None
June 19 June 20 July 3 July 4 July 20 July 21 Aug. 2 Aug. 3 Aug. 16 Aug. 17	Sept. 15	O 1041-1060 (C 321-340) O 1081-1100 (C 361-380) O 1101-1120 (C 381-400)	O 1061-1080 (C 341-360)	None

[a] Multiple dates (at each oil-addition period) represent cumulative additions of oil to rings on the dates listed.

[b] Control cores in parentheses represent data used in the statistical tests for significance (one-way analysis of variance).

TABLE 63 (continued)

RESULTS OF OIL ADDITION AT 1000 ppm ON THREE SPECIES OF INTERTIDAL HARPACTICOID COPEPODS

		Halectinosoma gothiceps (Type 4)		
Dates of[a] oil addition to experimental areas	Dates of collection	Cores with no significant difference between number of copepods ($\alpha = .01$)	Cores with significantly more copepods in oiled sample ($\alpha = .01$)	Cores with significantly more copepods in unoiled sample ($\alpha = .01$)
June 19 June 20	July 3-5	O 81-100 (C 1-20)[b] O 101-120 (C 21-40) O 141-160 (C 61-80)	None	O 121-140 (C 41-60)
June 19 June 20 July 3 July 4	July 18	O 321-340 (C 81-100) O 361-380 (C 121-140)	O 341-360 (C 101-120) O 381-400 (C 141-160)	None
June 19 June 20 July 3 July 4 July 20 July 21	Aug. 2	None	O 561-580 (C 161-180) O 581-600 (C 181-200) O 601-620 (C 201-220) O 621-640 (C 221-240)	None
June 19 June 20 July 3 July 4 July 20 July 21 Aug. 2 Aug. 3	Aug. 16	O 801-820 (C 241-260) O 841-860 (C 281-300)	O 821-840 (C 261-280) O 861-880 (C 301-320)	None
June 19 June 20 July 3 July 4 July 20 July 21 Aug. 2 Aug. 3 Aug. 16 Aug. 17	Sept. 15	O 1041-1060 (C 321-340) O 1061-1080 (C 341-360) O 1081-1100 (C 361-380) O 1101-1120 (C 381-400)	None	None

[a] Multiple dates (at each oil-addition period) represent cumulative additions of oil to rings on the dates listed.

[b] Control cores in parentheses represent data used in the statistical tests for significance (one-way analysis of variance).

TABLE 63 (continued)

RESULTS OF OIL ADDITION AT 1000 ppm ON THREE SPECIES OF INTERTIDAL HARPACTICOID COPEPODS

		Heterolaophonte sp. (Type 10)		
Dates of[a] oil addition to experimental areas	Dates of collection	Cores with no significant difference between number of copepods ($\alpha = .01$)	Cores with significantly more copepods in oiled sample ($\alpha = .01$)	Cores with significantly more copepods in unoiled sample ($\alpha = .01$)
June 19 June 20	July 3-5	O 81-100 (C 1-20)[b] O 101-120 (C 21-40) O 121-160 (C 41-60)	None	O 141-160 (C 61-80)
June 19 June 20 July 3 July 4	July 18	O 321-340 (C 81-100) O 341-360 (C 101-120) O 361-380 (C 121-140) O 381-400 (C 141-160)	None	None
June 19 June 20 July 3 July 4 July 20 July 21	Aug. 2	O 561-580 (C 161-180)	O 581-600 (C 181-200) O 601-620 (C 201-220) O 621-640 (C 221-240)	None
June 19 June 20 July 3 July 4 July 20 July 21 Aug. 2 Aug. 3	Aug. 16	O 801-820 (C 241-260) O 821-840 (C 261-280) O 841-860 (C 281-300)	O 861-880 (C 301 320)	None
June 19 June 20 July 3 July 4 July 20 July 21 Aug. 2 Aug. 3 Aug. 16 Aug. 17	Sept. 15	O 1041-1060 (C 321-340) O 1061-1080 (C 341-360) O 1081-1100 (C 361-380) O 1101-1120 (C 381-400)	None	None

[a] Multiple dates (at each oil-addition period) represent cumulative additions of oil to rings on the dates listed.

[b] Control cores in parentheses represent data used in the statistical tests for significance (one-way analysis of variance).

TABLE 64

RESULTS OF OIL ADDITION AT 2000 ppm ON THREE SPECIES OF INTERTIDAL HARPACTICOID COPEPODS FROM PORT VALDEZ, ALASKA, SUMMER - 1974

Cores with prefix O are experimental cores subjected to oil addition; those with prefix of C are unoiled Prudhoe Bay crude oil controls. See Methods Section for oil amendment and statistical procedures.

		Harpacticus uniremis (Type 1)		
Dates of[a] oil addition to experimental areas	Dates of collection	Cores with no significant difference between number of copepods ($\alpha = .01$)	Cores with significantly more copepods in oiled sample ($\alpha = .01$)	Cores with significantly more copepods in unoiled sample ($\alpha = .01$)
June 19 June 20	July 3-5	O 161-180 (C 1-20)[b] O 181-200 (C 21-40) O 201-220 (C 41-60) O 221-240 (C 61-80)	None	None
June 19 June 20 July 3 July 4	July 18	O 401-420 (C 81-100) O 421-440 (C 101-120) O 441-460 (C 121-140) O 461-480 (C 141-160)	None	None
June 19 June 20 July 3 July 4 July 20 July 21	Aug. 2	O 681-700 (C 201-220)	O 641-660 (C 161-180)	O 661-680 (C 181-200) O 701-720 (C 221-240)
June 19 June 20 July 3 July 4 July 20 July 21 Aug. 2 Aug. 3	Aug. 16	O 881-900 (C 241-260) O 921-940 (C 281-300)	None	O 921-920 (C 281-300) O 941-960 (C 301-320)
June 19 June 20 July 3 July 4 July 20 July 21 Aug. 2 Aug. 3 Aug. 16 Aug. 17	Sept. 15	O 1181-1200 (C 381-400)	O 1121-1140 (C 321-340) O 1141-1160 (C 341-360) O 1161-1180 (C 361-380)	None

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[a] Multiple dates (at each oil-addition period) represent cumulative additions of oil to rings on the dates listed.

[b] Control cores in parentheses represent data used in the statistical tests for significance (one-way analysis of variance).

TABLE 64 (Continued)

RESULTS OF OIL ADDITION AT 2000 ppm ON THREE SPECIES OF INTERTIDAL HARPACTICOID COPEPODS

		Halectinosoma gothiceps (Type 4)		
Dates of[a] oil addition to experimental areas	Dates of collection	Cores with no significant difference between number of copepods (α - .01)	Cores with significantly more copepods in oiled sample (α = .01)	Cores with significantly more copepods in unoiled sample (α = .01)
June 19 June 20	July 3-5	O 161-180 (C 1-20)[b] O 181-200 (C 21-40)	None	O 201-220 (C 41-60) O 221-240 (C 61-80)
June 19 June 20 July 3 July 4	July 18	O 401-420 (C 81-100) O 421-440 (C 101-120) O 441-460 (C 121-140) O 461-480 (C 141-160)	None	None
June 19 June 20 July 3 July 4 July 20 July 21	Aug. 2	O 641-640 (C 161-180) O 681-700 (C 201-220)	O 701-720 (C 221-240)	O 661-680 (C 181-200)
June 19 June 20 July 3 July 4 July 20 July 21 Aug. 2 Aug. 3	Aug. 16	O 881-900 (C 241-260) O 901-920 (C 261-280) O 921-940 (C 281-300) O 941-960 (C 301-320)	None	None
June 19 June 20 July 3 July 4 July 20 July 21 Aug. 2 Aug. 3 Aug. 16 Aug. 17	Sept. 15	O 1121-1140 (C 321-340) O 1161-1180 (C 361-380) O 1181-1200 (C 381-400) O 1141-1160 (C 341-360)	None	None

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[a] Multiple dates (at each oil-addition period) represent cumulative additions of oil to rings on the dates listed.

[b] Control cores in parentheses represent data used in the statistical tests for significance (one-way analysis of variance).

TABLE 64 (Continued)

RESULTS OF OIL ADDITION AT 2000 ppm ON THREE SPECIES
OF INTERTIDAL HARPACTICOID COPEPODS

		Heterolaophonte sp. (Type 10)		
Dates of[a] oil addition to experimental areas	Dates of collection	Cores with no significant difference between number of copepods (α = .01)	Cores with significantly more copepods in oiled sample (α = .01)	Cores with significantly more copepods in unoiled sample (α = .01)
June 19 June 20	July 3-5	O 161-180 (C 1-20)[b] O 181-200 (C 21-40) O 201-220 (C 41-60)	None	O 221-240 (C 61-80)
June 19 June 20 July 3 July 4	July 18	O 401-420 (C 81-100) O 421-440 (C 101-120) O 441-460 (C 121-140) O 461-480 (C 141-160)	None	None
June 19 June 20 July 3 July 4 July 20 July 21	Aug. 2	O 641-660 (C 161-180) O 681-700 (C 201-220)	O 661-680 (C 181-200) O 701-720 (C 221-240)	None
June 19 June 20 July 3 July 4 July 20 July 21 Aug. 2 Aug. 3	Aug. 16	O 881-900 (C 241-260) O 901-920 (C 261-280) O 921-940 (C 281-300) O 941-960 (C 301-320)	None	None
June 19 June 20 July 3 July 4 July 20 July 21 Aug. 2 Aug. 3 Aug. 16 Aug. 17	Sept. 15	O 1121-1140 (C 321-340) O 1141-1160 (C 341-360) O 1181-1200 (C 381-400)	O 1161-1180 (C 361-380)	None

[a] Multiple dates (at each oil-addition period) represent cumulative additions of oil to rings on the dates listed.

[b] Control cores in parentheses represent data used in the statistical tests for significance (one-way analysis of variance).

one oiled ring at the August 2 collection. At the August 16 collection, there were significantly more *H. uniremis* in two of the control rings. In the final collection there were significantly more *H. uniremis* in three of the oiled rings (Table 64; Figure 24).

Halectinosoma gothiceps in the experimental rings subjected to 2000 ppm of crude oil were not adversely affected. As was the case for 500 and 1000 ppm of oil, the numbers of *H. gothiceps* were generally higher within the oiled rings throughout the experimental period (Figure 25; Appendix A Tables 1 through 5). However, throughout the period, significantly ($\alpha = .01$) more *H. gothiceps* occurred in only one of the oiled rings (August 2) and two control rings (July 4 and August 2) (Table 64; Figure 25). The response of *Heterolaophonte* sp. 2000 ppm of crude oil was similar to that found for *H. gothiceps*. One control ring collected on July 4 showed significantly ($\alpha = .01$) more individuals. Two oiled rings collected on August 2 and one on September 15 showed significantly ($\alpha = .01$) more *Heterolaophonte* sp. (Table 64; Figure 26).

Analyses of variance for all data discussed above are presented in Appendix A Tables 1 through 5. Levels of significance at the 95% confidence limits are also included in these Tables for further comparison; frequently oiled rings showed significantly more individuals at this confidence level.

EXPERIMENT 2 - *Chronic oil-addition experiment of the long-range effect of a low concentration of Prudhoe Bay crude oil (200 ppm) on the density of three species of sediment-dwelling harpacticoid copepods.*

Experimental Procedure and Sampling

Eleven glass rings, each of the same dimensions as that used in Experiment 1, were pressed gently into the sediment site adjacent to the rings situated for the former study. Four of these rings served as controls; the rest of the rings were subjected to oil additions at a concentration of 200 ppm.

During the low tides of June 19 through 23, July 3 through 7, July 20 through 25, August 1 through 5, and August 16 through 20, 1974, the experimental rings were filled to a height of 3 cm with sea water, and

0.10 ml (200 ppm) of Prudhoe Bay crude oil was added with a volumetric pipette. The oil formed a slick which floated on the sea water in each ring. The sea water percolated through the sediment, and the oil slick settled on the sediment. The controls received sea water only.

No samples were taken during the entire period of oil additions. On 15 September 1974, 20 cores (2 cm in diameter) were taken from each of the four control rings and four of the test rings. The upper centimeter of sediment from each of these cores was preserved in 10% buffered formalin and returned to the laboratory in Fairbanks. Rose Bengal was added to each sample container, the material washed through 60 micron-Nitex screen, and examined with a dissection microscope. The copepods *Harpacticus uniremis*, *Halectinosoma gothiceps*, and *Heterolaophonte* sp. were separated and counted. An analysis of variance (Olivetti Underwood Programa 101, program 6.10) was used to compare the number of copepods in the test and control rings. The first centimeter of sediment was removed from the three additional rings for trace metal analysis (Section VIII).

Results

Significantly more (α = .01) *Harpacticus uniremis* occurred in two of the oiled test rings than in the corresponding controls. In the other sets of oil rings no significant differences could be detected, although more copepods were found in them as compared to the controls (Table 65; Figure 24).

There were significantly more (α = .01) *Halectinosoma gothiceps* in all four of the oiled test rings as compared to the control rings (Table 65; Figure 25). *Heterolaophonte* sp. showed significantly (α = .01) more copepods in one of the control rings, and more copepods were found in two of the other control rings as compared to the oiled rings (Table 65; Figure 26). Significance at the 95% level is included for comparison.

General Results of All Meiofaunal Oil Experiments

A summarization of the basic data from the oil experiments is found in Table 66. The great increase of *Harpacticus uniremis* and *Halectinosoma gothiceps* in most of the oiled rings as compared to the controls at the termination of the experiments can be clearly seen there.

TABLE 65

ANALYSIS OF VARIANCE OF THE NUMBERS OF EACH OF THREE SPECIES OF COPEPODS, IN CONTROL AND TEST (OIL AMENDED) RINGS. CHRONIC OIL-ADDITION EXPERIMENT. COLLECTION OF SEPTEMBER 15, 1974.

C = control, unoiled cores; X = experimental, oiled cores; chronic addition dosage; df = degrees of freedom; F = F ratio.

					Harpacticus uniremis (Type 1)			
Core Numbers	Concen. of Oil (PPM)	Mean No. of Copepods	Source of Variation	df	Mean Square	F	Signif. at 95% Level[a]	Signif. at 99% Level[b]
C 321-340	0	6.5	Sample Means	1	140.6			
X 1-20	200	10.3	Individ. Means	38	55.1	2.5	No	No
C 341-360	0	3.2	Sample Means	1	455.6			
X 21-40	200	10.0	Individ. Means	38	21.6	21.0	Yes	Yes
C 361-380	0	5.0	Sample Means	1	245.0			
X 41-60	200	9.9	Individ. Means	38	17.4	14.0	Yes	Yes
C 381-400	0	6.5	Sample Means	1	302.5			
X 61-80	200	12.0	Individ. Means	38	35.6	8.4	Yes	No

[a] Significant at 95% level; $F_\alpha(2)1,38=5.44$

[b] Significant at 99% level; $F_\alpha(2)1,38=8.89$

TABLE 65 (Continued)

ANALYSIS OF VARIANCE OF THE NUMBERS OF EACH OF THREE SPECIES OF COPEPODS, IN CONTROL AND TEST (OIL AMENDED) RINGS. CHRONIC OIL-ADDITION EXPERIMENT.

			Halectinosoma gothiceps (Type 4)					
Core Numbers	Concen. of Oil (PPM)	Mean No. of Copepods	Source of Variation	df	Mean Square	F	Signif. at 95% Level[a]	Signif. at 99% Level[b]
C 321-340	0	22.6	Sample Means	1	10304.1			
X 1-20	200	54.7	Individ. Means	38	458.5	22.4	Yes	Yes
C 341-360	0	20.0	Sample Means	1	28729.6			
X 21-40	200	73.6	Individ. Means	38	670.6	42.9	Yes	Yes
C 361-380	0	22.5	Sample Means	1	35224.2			
X 41-60	200	81.9	Individ. Means	38	257.3	136.8	Yes	Yes
C 381-400	0	22.8	Sample Means	1	25704.9			
X 61-80	200	73.5	Individ. Means	38	634.3	40.5	Yes	Yes

[a] Significant at 95% level; $F_{\alpha}(2)1,38=5.44$

[b] Significant at 99% level; $F_{\alpha}(2)1,38=8.89$

TABLE 65 (Continued)

ANALYSIS OF VARIANCE OF THE NUMBERS OF EACH OF THREE SPECIES OF COPEPODS, IN CONTROL AND TEST (OIL AMENDED) RINGS. CHRONIC OIL-ADDITION EXPERIMENT.

			Heterolaophonte sp. (Type 10)					
Core Numbers	Concen. of Oil (PPM)	Mean No. of Copepods	Source of Variation	df	Mean Square	F	Signif. at 95% Level[a]	Signif. at 99% Level[b]
C 321-340	0	11.5	Sample Means	1	84.1			
X 1-20	200	8.6	Individ. Means	38	30.5	2.7	No	No
C 341-360	0	10.1	Sample Means	1	102.4			
X 21-40	200	6.9	Individ. Means	38	16.0	6.3	Yes	No
C 361-380	0	10.0	Sample Means	1	22.5			
X 41-60	200	11.5	Individ. Means	38	29.5	0.7	No	No
C 381-400	0	10.4	Sample Means	1	108.9			
X 61-80	200	7.1	Individ. Means	38	9.0	12.0	Yes	Yes

[a] Significant at 95% level; $F_{\alpha}(2)1,38=5.44$

[b] Significant at 99% level; $F_{\alpha}(2)1,38=8.89$

TABLE 66

EFFECTS OF OIL ON COPEPOD POPULATIONS FROM AN AREA OF 3.14 CM^2 IN PORT VALDEZ

	Control				500 ppm oil				1000 ppm oil			
Date	Total^{a} Number Copepod	Mean	♀ with eggs	Copulating pairs	Total Number Copepod	Mean	♀ with eggs	Copulating pairs	Total Number Copepod	Mean	♀ with eggs	Copulating pairs
a. *Harpacticus uniremis*												
July 3, 1974	386^{a}	5.9	-	-	637^{c}	8.1	-	-	477	6.0	-	-
July 18, 1974	379	4.7	-	-	524^{2}	6.6	-	-	463	5.8	-	-
Aug 2, 1974	679	8.5	-	-	647	8.1	-	-	484	6.1	-	-
Aug 16, 1974	583	7.3	-	-	675	8.4	-	-	621	7.8	-	-
Sept 15, 1974	426	5.3	1	-	733	9.2	-	-	595	7.4	-	-
b. *Halectinosoma gothiceps*												
July 3, 1974	2448^{b}	37.7	40	68	3162^{c}	40.0	17	40	2343	29.3	28	37
July 18, 1974	2866	35.8	22	55	3838^{c}	48.6	13	24	3535	44.2	22	21
Aug 2, 1974	2022	25.3	13	5	3354	41.9	3	-	4152	51.9	3	1
Aug 16, 1974	1984	24.8	22	-	2619	32.7	66	1	3241	40.5	43	3
Sept 15, 1974	1759	22.0	24	21	2361	29.5	17	21	1759	22.0	20	3
c. *Heterolaophonte* sp.												
July 3, 1974	2058^{b}	31.7	149	2	2082^{c}	26.4	23	-	2002	25.0	76	-
July 18, 1974	2099	26.2	6	-	1489^{c}	18.8	-	-	1865	23.3	6	-
Aug 2, 1974	1056	13.2	-	-	1457	18.2	-	-	1619	20.2	-	-
Aug 16, 1974	838	10.5	-	-	1114	13.9	-	-	1115	13.9	-	-
Sept 15, 1974	841	10.5	-	-	841	10.5	-	-	859	10.7	1	-

[a] = Unless otherwise noted, 80 samples were counted.

[b] = 65 samples counted

[c] = 79 samples counted

TABLE 66 (Continued)

EFFECTS OF OIL ON COPEPOD POPULATIONS FROM AN AREA OF 3.14 CM^2 IN PORT VALDEZ. SEE METHODS FOR OIL-AMMENDMENT PROCEDURES.

Date	2000 ppm oil				Chronic oils			
	Total[a] Number Copepod	Mean	♀ with eggs	Copulating pairs	Total Number Copepod	Mean	♀ with eggs	Copulating pairs
a. *Harpacticus uniremis*								
July 3, 1974	499	6.2	-	-				
July 18, 1974	455	5.7	-	-				
Aug 2, 1974	384	4.8	-	-				
Aug 16, 1974	299	3.7	-	-				
Sept 15, 1974	803	10.0	-	-	844	10.6	-	-
b. *Halectinosoma gothiceps*								
July 3, 1974	2306	28.8	12	46				
July 18, 1974	3271	40.9	18	34				
Aug 2, 1974	2826	35.3	2	-				
Aug 16, 1974	2221	27.8	44	2				
Sept 15, 1974	2065	25.8	12	18	5775	72.2	101	109
c. *Heterolaophonte* sp.								
July 3, 1974	2127	26.6	48	-				
July 18, 1974	1834	22.9	2	-				
Aug 2, 1974	1408	17.6	-	-				
Aug 16, 1974	977	12.2	-	-				
Sept 15, 1974	1148	14.4	5	-	683	8.5	7	-

An analysis of the percent composition of copepod species with time after oil additions is presented in Table 67 and Figure 27. Essentially no change in percent composition of *Harpacticus uniremis* occurs until August 2 at which time a considerable increase in percent composition is noted in the control and the 500 ppm cores. A slight increase in percent composition of this species is noted in the oil cores at the last collection in September 15. A general increase in percent composition of *H. gothiceps* is noted throughout the initial phases of the experiment with a decrease in percent composition noted at 1000 and 2000 ppm in the September 15 collection. A general decrease in percent composition is noted for *Heterolaophonte* sp. for much of the experimental period with a slight upward trend for the controls and the oiled plots (1000 and 2000 ppm).

Data on the affect of oil on all species of copepods observed in reproductive activity (bearing eggs, copulating) are presented in Tables 66 and 68. Table 68 shows the number of cores sampled in which no reproductive activity was noted. A low number of copepods in the table indicates a high rate of reproductive activity. Throughout most of the experiment the controls showed a higher rate of activity than that found for the oil cores. Only in the Chronic Oil cores were there a greater number of copepods undergoing reproductive activity. This was true primarily for *H. gothiceps* and to a lesser extent for *Heterolaophonte* sp. A prolongation of the egg-laying period through September may have occured for *Heterolaophonte* sp. living in oiled sediments (Table 66).

DISCUSSION

The three species of copepods exposed to various levels of oil in the field increased in density within a variable number of oiled plots. Such increases in numbers were especially obvious in the experiments where copepods were subjected to chronic low-level doses of crude oil (Tables 62, 63 and 64: Figs. 23, 24 and 25). Two of the species, *Halectinosoma gothiceps* and *Heterolaophonte* sp., also demonstrated an increase in reproductive activity in oiled sediments, although the former only showed this in the chronically oiled plots. The statistically significant ($\alpha = .01$) increase

TABLE 67

POPULATIONS OF COPEPODS EXPRESSED AS A % OF THE TOTAL NUMBER PRESENT IN CONTROL AND OIL SAMPLES. SEE METHODS FOR OIL-AMMENDMENT PROCEDURES.

Date of Collection	Control	500 ppm oil	1000 ppm oil	2000 ppm oil
a. *Harpacticus uniremis*				
July 3, 1974	7.89	10.83	9.89	10.12
July 18, 1974	7.09	8.96	7.90	8.18
Aug 2, 1974	18.07	11.85	7.74	8.32
Aug 16, 1974	17.12	15.31	12.48	8.55
Sept 15, 1974	14.08	18.63	18.52	20.00
b. *Halectinosoma gothiceps*				
July 3, 1974	50.04	53.77	48.60	46.76
July 18, 1974	53.63	65.60	60.29	58.83
Aug 2, 1974	53.82	61.45	66.38	61.20
Aug 16, 1974	58.27	59.41	65.12	63.51
Sept 15, 1974	58.13	60.00	54.75	51.42
c. *Heterolaophonte* sp.				
July 3, 1974	42.07	35.40	41.52	43.13
July 18, 1974	39.28	25.45	31.81	32.99
Aug 2, 1974	28.11	26.69	25.88	30.49
Aug 16, 1974	24.61	25.27	22.40	27.94
Sept 15, 1974	27.79	21.37	26.74	28.59

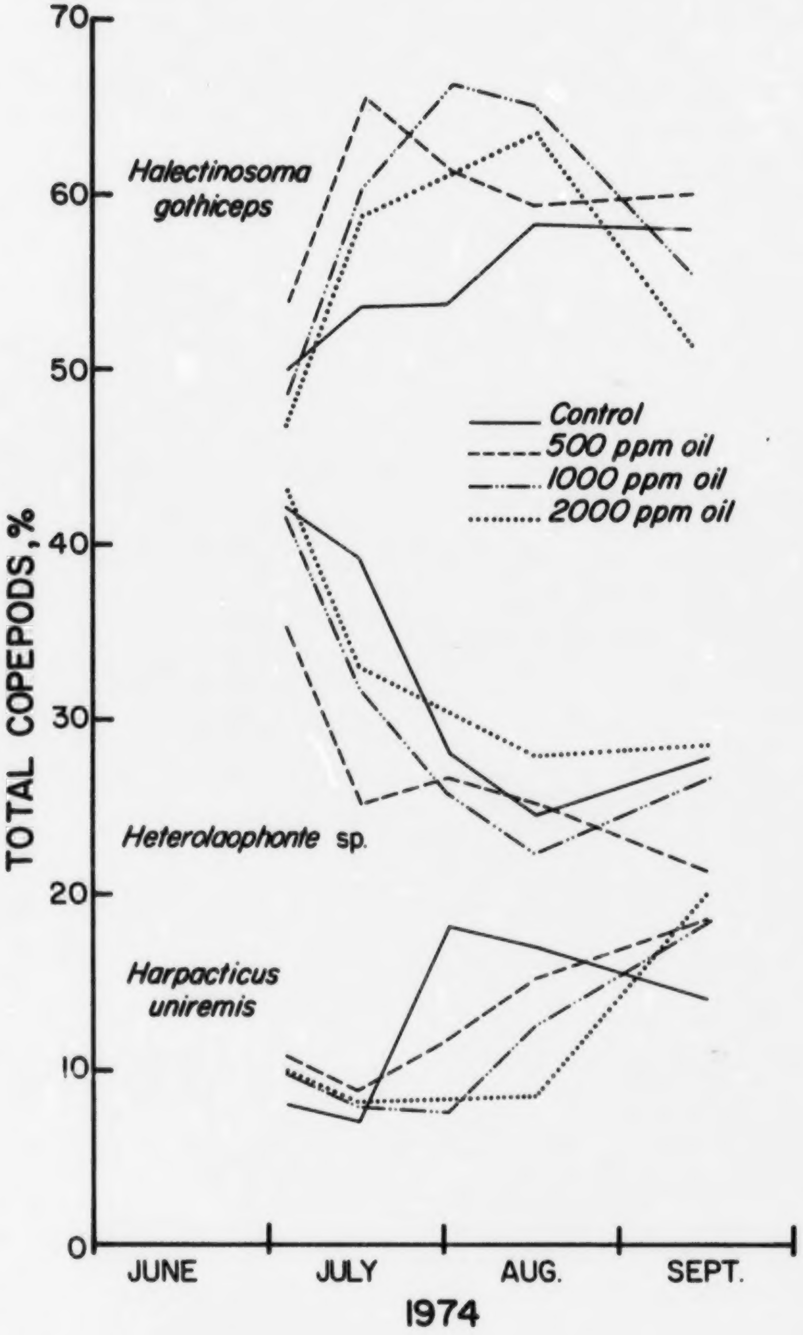

Figure 27. The percent composition of each of three species of copepods at the oil sampling site on Island Flats. See Methods for oil-ammendment and collection dates.

TABLE 68

OIL EXPERIMENT. NUMBER OF CORES[a] WITH NO EGGS OR COPULATING COPEPODS PRESENT (COMBINED SPECIES). A LOW NUMBER IN THE TABLE INDICATES A HIGH RATE OF REPRODUCTIVE ACTIVITY.

Date	Control	500 ppm oil	1000 ppm oil	2000 ppm oil	Chronic oil
July 3, 1974	14[b]	43[c]	21	38	-
July 18, 1974	43	60[c]	52	39	-
Aug 2, 1974	66	77	77	78	-
Aug 16, 1974	66	46	51	49	-
Sept 15, 1974	53	51	63	53	22

[a] = total number of cores counted equals 80 unless otherwise noted.

[b] = total of 65 cores

[c] = total of 79 cores

in numbers of individuals in conjunction with the increase in reproductive activity for *H. gothiceps* suggest that the density increments in the oil rings are a reflection of this heightened reproductive activity. On the other hand, the slight increase in numbers of *H. uniremis* in some of the oiled plots may be the result of an attraction of the copepod to oil since this species was not reproducing during the experimental period (see Section VII for an analysis of the life history of *H. uniremis*). The modest increases in density of *Heterolaophonte* sp. in some of the oiled rings may also be due, in part, to the attraction of this copepod to oil. Further laboratory work designed to test the responses of the three species of copepods to oil in sediments is suggested to verify the field data. The only published information on the attraction of a crustacean to oil is discussed by Blumer (1972)[110] in which he cites evidence for the attraction of the lobster (*Homarus*) to crude oil distillates. He suggests that an oil spill may attract the lobster away from their normal food, and guide it to the spill area where it is likely to be contaminated or killed.

A possible attraction to and nutritive relationship between Prudhoe Bay crude oil and two of the species of copepods studied (*Halectinosoma gothiceps* and *Heterolaophonte* sp.) are suggested by the data on increased reproductive activity following a period of chronic oil addition. Several species of pelagic copepods have been shown to ingest small particles of oil from the water column without harm (Conover, 1971[111]; Parker *et al.*, 1971[112]), although all of the copepods examined apparently passed the oil through their digestive tracts in an unchanged condition. However, bacteria, a major source of food for sediment-dwelling copepods (see Sections VI and IX for discussions and review of the literature), are able to degrade oil, and the continuing presence of available oil generally results in an increase in bacterial biomass in the marine environment. Furthermore, an enrichment of hydrocarbon degrading bacteria has been found to occur in intertidal sediments within four to sixteen days after an oil spill (Pierce *et al.*, 1975)[113]. No increase in bacterial numbers was observed in the experimentally oiled plots in Port Valdez. However, it is suggested in Section IX that changes in bacterial species present and/or increased turnover due to grazing might occur without noting changes in bacterial standing crop. Thus, the increases in copepod populations noted in our experiments in Port Valdez might be explained in terms of direct cropping by these copepods on bacteria.

Our investigations indicate that oil applied at low tide to beaches in Port Valdez will not readily penetrate the fine sediments there, and, in fact, will be rapidly removed by tidal waters (Section VIII). Harpacticoid copepods live primarily in the upper two centimeters of sediment (Section VI), and are therefore present in the same strata that oil-bacterial interactions are taking place. Thus, copepods could take immediate advantage of any rapid growth of bacteria occurring in the sediments before the oil is physically removed. (See Sections VIII and XI for comments on oil degradation rates in Port Valdez sediments.) Direct utilization of oil as a carbon source cannot be totally excluded as a possibility.

The sediment-dwelling copepods considered here were not adversely affected by the concentrations of Prudhoe Bay crude oil added to the sediments in the course of experiments described above. In work accomplished in British Columbia, harpacticoid copepods, and meiofauna in general, on a beach were also apparently unaffected directly after an oil spill and for up to one year later. These results are in contrast to data derived from laboratory experiments that have shown crude oil and crude oil fractions to be toxic to various species of copepods (Barnett and Kontogiannis, 1975[114]; Evans and Rice, 1974[109]; Mironov, 1968[115]; Nelson-Smith, 1972[116]). Further experimental work is essential to comprehend the results of our copepod-oil experiments in Port Valdez. In addition, long-term information is needed to determine the effects of the continued presence of soluble oil fractions on sediment-dwelling copepods and other meiofauna.

SECTION XI

HYDROCARBON STUDIES ON SEDIMENT BEACHES IN PORT VALDEZ

GENERAL INTRODUCTION

This chapter describes a study of the uptake and release of intentionally added oil by intertidal sediments and by the bivalve mollusk *Macoma balthica*. This study was undertaken to gain knowledge of how these elements of the intertidal environment in Port Valdez respond to light, occasional strandings of petroleum. The approach used here is essentially a chemical one. Chemical measurements of the concentrations of petroleum in sediment and in depurated *M. balthica* were made at intervals following a series of intentional oilings. From these measurements we know that the petroleum concentration first rises, then declines following the application of oil. We do not know from this work whether that decline is due to the chemical breakdown of the oil or to its transfer unchanged to other parts of the environment. Nor has this work revealed in any great detail the effects of the oiling on *M. balthica*. Answers to these questions await other studies. However, this study has produced important and useful information about how long petroleum, when applied in a specific way, is retained by sediments and by an organism that feeds directly on that sediment.

SEDIMENT STUDIES

Introduction

The interaction of petroleum and its constituent hydrocarbons with sediments is a subject which has recently been the focus of considerable scientific attention. Impetus has come from concern about the ability of sediment to function as a sink and reservoir of petroleum following actual and potential oil spills. There exists a large body of literature which describes ambient levels of hydrocarbons in the surficial benthic sediments of marine and aquatic environments subject to various degrees of pollution. Typical of these are the reports of Clark and Blumer (1967)[117], Farrington and Quinn (1973)[118], Giger *et al.* (1974)[119], and

Zafiriou (1973)[120]. These studies have used a synoptic approach to get at hydrocarbon distribution. In each case a suite of samples has been collected over a given geographic area in a short (relative to the usual rates of hydrocarbon accumulation in sediments) period of time. Sources, sinks, and transport processes of hydrocarbons are then inferred from their geographic distribution. Detailed discussions of criteria for distinguishing biogenic from petroleum hydrocarbons have appeared (Clark, 1974[121]; Blumer and Sass 1972[122]).

Another approach to understanding the interaction of petroleum with sediments has been to study the chemical (Meyers and Quinn, 1973)[123] and biological (Johnston, 1970)[92] factors which influence this interaction.

Here we report results of yet another approach to understanding the interaction of petroleum and sediments: an experiment in which the uptake and release of a crude petroleum by an intertidal sediment following a series of intentional oilings has been measured. Uptake and release experiments are not new. This approach has been used to study the interaction of hydrocarbons with biota both in the laboratory (Lee *et al.*, 1972[124]; Stegeman and Teal, 1973[125]) and in the field (Morris, 1973)[126] This same time series approach has been used to follow the uptake and release of petroleum by sediments following unintentional oil spills (Blumer and Sass, 1972[122]; Mayo *et al.*, 1974[127]). In our experiment, oil was intentionally spread in a manner which simulated the stranding of a light oil slick on an intertidal mud flat. The experiment was carried out during the summer of 1974 at Valdez, Alaska. This site was of particular interest because this previously non-industrialized area will soon become the location of the southern terminus of the trans Alaska oil pipeline and a supertanker port. However, we believe that conclusions can be reached from the results of this experiment that are of much more general applicability than to the location at which the observations were made.

Methods

Site -

All experiments were carried out on Island Flats, an embayed portion of Port Valdez; specifically the area of study was located on Flats north of Ammunition Island (see Sect. IV for details and location of the study area.

Experimental Design -

The objective of the experiment was to simulate a pollution event in which a sheen of oil was stranded on a mud flat by each receeding tide for several days. To contain added oil and to designate control areas, a number of rectangular containment frames (topless and bottomless boxes) constructed of sheet aluminium were placed on the flat. Each frame measured 28 cm wide by 62 cm long by 5 cm high. The total volume of each was 8.7 ℓ. The frames were placed directly on the sediment in an area of the flat which had no marked inhomogeneity. One-half of the frames were considered controls and to these no oil was added. To the others oil was added once daily for five successive days while the frames were exposed by low tide. In the oiling operation a frame was filled with sea water from a lower portion of the flat, and then a volume of Prudhoe Bay crude oil was added by syringe. Over a period of a few minutes the water trickled out around the bottom of the frame. Some of the oil escaped with the water but an apparently uniform film of oil was deposited on the surface of the sediment. In controls, only water was added to the frame. Of the oiled frames one half received 2.2 ml of oil daily (Experiment A - Table 69). The other half received 8.6 ml daily (Experiment B - Table 69). If the added oil had dispersed uniformly through water in the entire volume of the frame, the concentrations of oil would be 250 ppm and 1000 ppm, respectively. However, under the experimental conditions, dispersion was incomplete; most of the oil remained as surface slicks. If all of the oil had remained in the surface slicks, they would have contained 1.2 μl oil cm^{-2} and 5.0 μl oil cm^{-2}, respectively. These rates of oiling correspond (if the density of the oil is assumed to be 0.8 g ml^{-1}) to one ton per 100 square kilometers and one ton per 20 square kilometers. These are light rates of oiling; in both cases the slicks of oil were multi-colored, indicating that they were only a few molecules thick.

TABLE 69

CONCENTRATIONS OF HYDROCARBONS ISOLATED FROM SEDIMENTS. EXPERIMENT A CONSISTED OF OILING AT THE RATE OF 1.2 μl cm^2, EXPERIMENT B CONSISTED OF OILING AT THE RATE OF 5.0 μl cm^2.

Day	No. of Oil Applications	Concentration of Oil in Sediments μg g^{-1}	
		Experiment A	Experiment B
0	0	7[a]	6
3	2	12	530
5	4	33	420
7	5	76[a]	1700[a]
15	5	22	640
29	5	31	3900
44	5	5[a]	760[a]
60	5	14	14

[a] Chromatogram shown in Figure 29.

Sampling -

Samples of sediment and *Macoma balthica* were taken before oiling began and on the third, fifth, seventh, fifteenth, twenty-ninth, forty-fourth, and sixtieth days after the first oiling. On each occasion four samples were taken, one for each level of oiling and a blank for each of those. Each sediment sample consisted of all the sediment in a 5.0 cm square excavated to a depth of 1.0 cm. The sediment was placed in a pre-cleaned glass jar and frozen until analysis. Each sampling in the time series was made from a different containment frame. The remaining sediment in each was collected to a depth of 4 cm and screened to obtain *M. balthica*.

Analysis of Sediments -

Solvents were redistilled prior to use. Purity was established by concentrating *in vacuo* 400 ml of the redistilled solvent to approximately 1.0 ml. Five μl of the resulting solution was analysed by gas chromatography under the same conditions used for hydrocarbon samples. Only solvents which demonstrated little or no evidence of contamination by this method were used. Distilled H_2O was redistilled in glass from $KMnO_4$ and assayed for contamination by a procedure similar to that used for sediment samples.

A Varian 1520 gas chromatograph with dual column flame ionization detector was used in all analyses. The carrier gas (Helium) had a flow rate of 40 ml/min. All chromatograms were temperature programmed: the column was isothermal at 60°C for four minutes following injection, and then approached 270°C at 15°C min^{-1}. The columns were one-eighth inch by six feet stainless steel, packed with 1.5% OV-101 on 80/100 mesh Chromosorb W-HP.

Soxhlet extractions were done with 500 ml flat bottom flasks and 5 cm soxhlet extractors. Cellulose thimbles (Whatman 43x123 mm) were pre-extracted with 300 ml benzene/methanol 1/1 (v/v). Thimble extraction was continued until the *in vacuo* concentrated extract showed no evidence of contaminants on analysis by gas chromatography.

Silica gel and alumina were each activated at 250° C for two days and then deactivated with H_2O, 5% and 6% respectively. Hexane washed, oven dried glass wool was used to plug a nine inch pasteur pipet. The pipet and glass wool were rinsed with hexane before adding a hexane slurry of silica gel to approximately 3.5 cm above the glass wool. The column was completed by topping with another 3.5 cm of alumina in a hexane slurry. At least one column volume of hexane was flushed through the column before any sample was added.

Partially thawed sediment samples were loaded into dry-tared, pre-extracted cellulose extraction thimbles. While loading, the sediment was examined and obvious organisms removed with forceps. The sediment was extracted for 48 hours with 300 ml of an equal parts mixture of benzene and methanol. At least once midway through the extraction period, the sediment was stirred with a glass rod to preclude channeling effects.

The benzene/methanol solution was extracted in a 1000 ml separatory funnel with three 100 ml portions hexane. The combined hexane extracts were washed with 100 ml saturated aqueous NaCl and then dried with anhydrous Na_2SO_4 overnight.

The hexane solution was concentrated *in vacuo* to approximately 1.0 ml. During the final stages of concentration, powdered copper metal in hexane was added to remove elemental sulfur. After concentration the sample was loaded on a chromatography column and eluted with hexane. Two 4.0 ml fractions were collected. Chromatography of knowns showed that petroleum hydrocarbons were eluted in the first 4.0 ml fraction. The hexane fractions were evaporated to no less than 0.2 ml under a stream of nitrogen and analysis by gas chromatography was performed. Because of high concentrations of hydrocarbons, some samples were left at 4.0 ml volume.

Total weights of hydrocarbons extracted were determined by transferring the hydrocarbon solution to a tared sample vial and determining the solution volume from the density of hexane (0.66 g/ml). An aliquot of the solution was withdrawn (usually 100 μl), evaporated in air, and weighed on an electrobalance. These weights are expressed in μg of hydrocarbon extraced per gram of dry sediment.

Results

Table 69 shows the weights of hydrocarbons (and other non polar lipids) from sediments collected at various times after oiling. The weights are of the first column chromatographic fraction, which includes any petroleum hydrocarbons that are present. Figure 28 shows graphically the data of Table 69 for each of the rates of oiling. Figure 29 shows selected gas chromatograms of extracts from the two experiments.

Discussion

The weights of hydrocarbons extractable from sediments show a general trend of uptake and release during the course of the experiments. However, in neither Experiment A nor B is there a single maximum in the hydrocarbon concentration curve; both sets of data show considerable scatter. We feel that this scatter is inherent to the experimental design, which called for each sediment sample to be taken from a different containment frame. Although all of the frames were set out on an area of the mud flat that appeared uniform, it may be that non-apparent differences in the substratum affected its ability to take up and release hydrocarbons. Thus the various frame sites may have had inherently different characteristics.

In *both* experiments the hydrocarbon concentrations are high on day 29. Random scatter is a sufficient but unpleasing explanation for this result. Another line of evidence gives us confidence in the 3900 μg/g of hydrocarbon observed for day 29 of Experiment B (Table 69). The frame examined on day 29 of Experiment B showed the highest mortality of the clam *Macoma balthica* observed during the entire experiment (Table 70). In general, we found that high *M. balthica* mortality correlated well with high concentrations of hydrocarbons in the sediment. Details of studies of the uptake and release of hydrocarbons by *M. balthica* are reported in part two of this Section.

The five chromatograms reproduced in Figure 29 show the uptake and release of hydrocarbons in more detail than the weight data of Table 69. Chromatogram 1 shows the pre-experiment hydrocarbon content of the sediments. The peak assignments have been made on the basis of retention times using

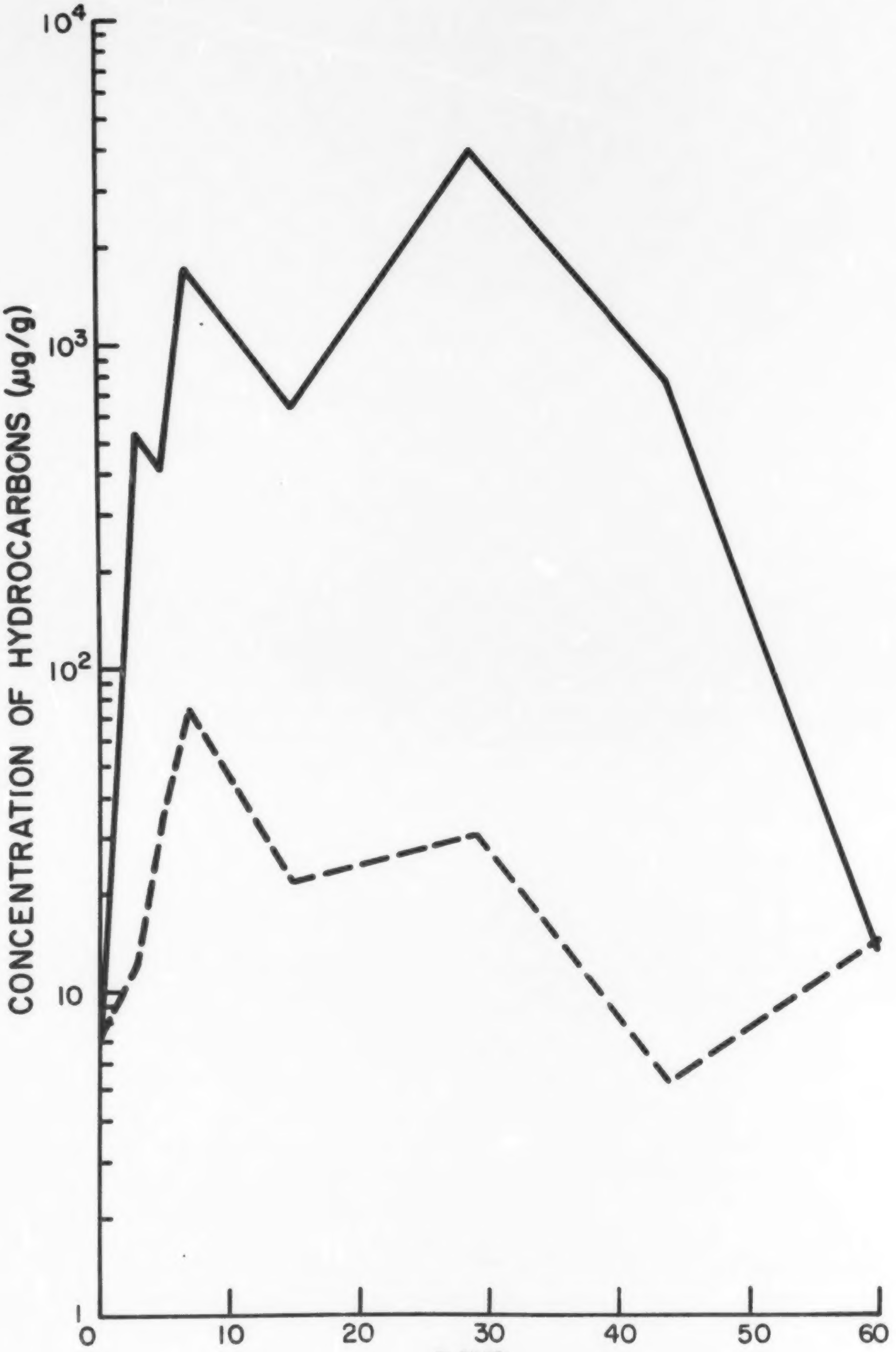

Figure 28. Concentrations of hydrocarbons isolated from sediments: dashed line is experiment A (250 ppm oil addition); full line is experiment B (1000 ppm oil addition).

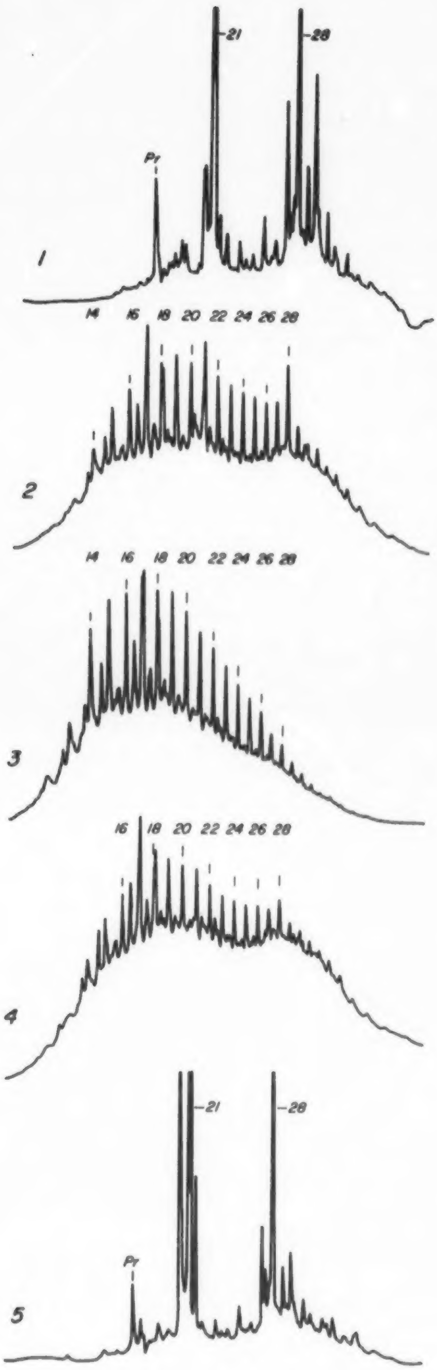

Figure 29. Selected gas chromatograms from experiments A and B: 1) pre-experiment hydrocarbon content of the sediments; 2) day 7 of experiment A; 3) day 7 of experiment B; 4) day 44 of experiment B; 5) day 44 of experiment A.

TABLE 70

NUMBER OF DEATHS OF *MACOMA BALTHICA* IN INTERTIDAL TEST FRAMES SUBJECTED TO 1.2 AND 5.0 μℓ oil/cm^2 FOR 5 DAYS AT PORT VALDEZ, ALASKA IN THE SUMMER OF 1974

Days after first oiling	Rate of oiling	Total number of *M. balthica*	Number of mortalities	Significant difference (95% confidence level)
0	0	367	0	-
	0	357	0	
3	1.2	464	0	No
	0	567	0	
3	5.0	418	0	No
	0	382	0	
5	1.2	431	0	No
	0	343	0	
5	5.0	340	3	No
	0	213	0	
7	1.2	466	0	No
	0	357	0	
7	5.0	329	21	Yes
	0	325	7	
9	1.2	427	0	No
	0	415	3	
9	5.0	441	17	Yes
	0	353	0	

TABLE 70 (Continued)

NUMBER OF DEATHS OF *MACOMA BALTHICA*

Days after first oiling	Rate of oiling	Total number of *M. balthica*	Number of mortalities	Significant difference (95% confidence level)
15	1.2	482	0	No
	0	391	0	
15	5.0	494	8	Yes
	0	411	0	
29	1.2	450	0	No
	0	273	1	
29	5.0	428	49	Yes
	0	407	1	
44	1.2	356	0	No
	0	295	0	
44	5.0	461	40	Yes
	0	209	0	
60	1.2	223	6	No
	0	262	0	
60	5.0	263	3	No
	0	329	2	

internal and external standards. The chromatogram is typical of biogenic hydrocarbons in recent shallow marine sediments. It consists of a relatively few large peaks and lacks the stair step pattern of n-alkanes and large unresolved envelope characteristic of petroleum. Chromatogram 1 shows the presence of pristane but not phytane, another indication of recent biogenic origin (Blumer and Snyder, 1965)[128].

Chromatogram 2 is from day 7 of Experiment A (Table 69). The general aspect of this chromatogram is of petroleum: large unresolved envelope and stair stepping n-alkane peaks. Pristane is not resolved from heptadecane leading to the tallest peak in the chromatogram. Phytane is now present, eluting immediately after octadcane. Two other peaks, those tentatively assigned to heneicosane and octacosane also rise above the general stair step pattern of the n-alkanes. These two peaks represent contributions from the background hydrocarbons as well as the added petroleum. This chromatogram shows a situation where the individual hydrocarbons of the added petroleum are in comparable concentration with the pre-existing hydrocarbons.

Chromatogram 3 is from day 7 of Experiment B (Table 69). The general aspect is, as in chromatogram 2, of petroleum. The heavier rate of oiling in Experiment B has made contributions to the heneicosane and octacosane peaks by the background biogenic hydrocarbons of chromatogram 1 undetectable. Chromatogram 3 is essentially that of the added Prudhoe Bay crude oil.

Chromatogram 4 is from day 44 of Experiment B (Table 69). The appearance here is of a petroleum which has undergone biological and physical degradation. Two factors indicate biodegradation. The ratio of areas of resolved peaks to unresolved envelope in chromatogram 4, as determined by planimetry, is 0.08. The comparable ratio for chromatogram 3 is 0.19. That is, there is a preferential diminution of the resolved peaks (largely n-alkanes) relative to the unresolved envelope. Given the general microbial preference for n-alkanes among possible hydrocarbon substrates, (Johnson, 1964)[129], the drop in the ratio suggests microbial consumption of the oil. Further evidence of selective loss of n-alkanes comes from the phytane, octadecane ratios in chromatograms 3 and 4. In 3 this ratio is

0.73; in 4 it is 1.26. Octadecane is being lost more rapidly than phytane. This is a second example of preferential consumption of n-alkanes. Not all of the loss of petroleum is from biodegradation. The decrease in total hydrocarbons from 1700 μg/g^{-1} to 760 μg/g^{-1} indicates that physical removal via evaporation and tidal action is also occurring.

Chromatogram 5 is for day 44 of Experiment B (Table 69). The chromatogram is quite similar to chromatogram 1. Petroleum residues are no longer detectable. The chromatograms for day 60 of both experiments are similar to 1 and 5.

Under the conditions of our experiment at the *Macoma balthica* site, biological and physical processes combined to remove most stranded oil from the top 1.0 cm of sediment during a period of about two months. Our conditions were such that the oil was very gently applied to the sediments. There was no wave action at the study site. No storms occurred during the course of the experiment. There was a general absence of mechanical forces pushing the oil into the sediment. From a nearby site in Port Valdez (Old Valdez) we have evidence (R. Gritz and Feder, unpublished observations) that petroleum can remain in similar sediments for several years. Oil, which had entered intertidal sediments when a large fuel storage tank at Valdez ruptured in 1964, was still detectable in 1974. Other workers (Blumer and Sass, 1972[122]; Mayo *et al.*, 1974[127]) have similarly found that petroleum which has penetrated into sediment is released over a period of years. We estimate that the concentration of petroleum remaining in the sediment at the end of the experimental period (day 60) to have been less than 1 μg g^{-1} We suggest that a key difference is that in the experiment reported here, the oil remained on, or very near the surface of the sediment from which it was rapidly removed by biodegradation, evaporation, and a gentle rinsing action of tidal waters. We cannot positively rule out the possibility that petroleum penetrated into the sediment to a depth greater than 1.0 cm. However, based on an experiment carried out simultaneously in an adjacent location, we doubt that such penetration occurred.

In the experimental plots used for the bacterial (Section IX) and meiofaunal (Section X) studies, Prudhoe Bay crude oil (2.5, 5.0, and 10 μl cm^{-2}) was added daily for five days. This regime of oil addition was repeated five times at bi-weekly intervals for three months. Twenty-six days after the final addition, sediment samples were collected from 1, 2, and 3 cm depths. Analysis of these samples showed hydrocarbon values at or near the background level (Table 71). Thus, under these oiling conditions, which were considerably more intense than any used in the main experiments, the penetration of added petroleum was slight.

A plot of the data of Table 69, assuming that the release of petroleum by the sediments is a first order process depending only on the concentration of the petroleum, indicates that the half life of oil in sediment under these conditions is on the order of a few weeks. Scatter in the data prevent a more precise measurement of this half life. We believe that the observed scatter is, at least in part, real and reflects non-uniformities in the sediment. The existence of such non-uniformities should surprise no one familiar with intertidal biology. Population densities of intertidal organisms often vary markedly in response to environmental changes that are not readily apparent.

MACOMA BALTHICA STUDIES

Simultaneously with the sediment studies described above, the effect of added oil on the intertidal bivalve mollusk *Macoma balthica*[*] was investigated. Judging from the results of one summer of field experimentation, it appears that *M. balthica* has potential as an indicator species for oil pollution.

It is not suggested that *Macoma balthica* be used as a universal approach to oil pollution assessment. Clearly, there are many situations where the use of *M. balthica* (or species of *Macoma*) or the entire concept of indicator species may be inappropriate. However, we do believe that our initial results warrant a detailed examination of the genus *Macoma* for use along with present indicator organisms.

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[*] The taxonomy of *M. balthica* remains an area of active research: E. V. Coan, *Veliger*, 14 (Supplement), 44-46 (1971). There is some indication that the Pacific and Atlantic populations are separate although closely related species. However, the bulk of available data favors a single species.

TABLE 71

HYDROCARBON CONCENTRATIONS IN SEDIMENT DEPTH PROFILES TAKEN AT ISLAND FLATS[a]

	Application Rates		
Sediment Depths	2.5 µl cm^{-2} (500 ppm)	5.0 µl cm^{-2} (1000 ppm)	10 µl cm^{-2} (2000 ppm)
	Hydrocarbon Concentrations[b]		
1 cm	6.4	4.2	7.0
2 cm	3.0	5.6	5.7
3 cm	2.4	19	5.5

[a] Sediment samples taken at the termination of the oiling experiment from plots used for meiofaunal (Section X) and bacterial (Section IX) studies. Prudhoe Bay crude oil was added to the plots for a period of three months.

[b] Concentration units are µg hydrocarbon per g of dry sediment.

The theory and practice of indicator organisms have been discussed in detail (Butler *et al*, 1972)[130]. Two groups of bivalves which have received considerable attention are oysters and mussels. The characteristics of these organisms which make them suitable as indicators throughout most of their range include the knowledge of their taxonomy, the wealth of background knowledge of their general biology, and their filter feeding habit which causes them to concentrate hydrocarbons from the water column. The qualities that recommend *Macoma balthica* as an indicator are different and thus would make its use complementary to oysters or mussels. *Macoma balthica* is in large part a deposit feeder (Brafield and Newell, 1961)[131] and thus can be expected to concentrate oil which is in or on bottom sediments. The relationship between oil in sediment and *M. balthica* mortality lets the latter provide an easily measured indication of the presence of polluting oil.

Methods

Mortalities of *Macoma balthica* which had been subjected to the experimental procedures described above, were measured. Gaping individuals and valves with elastic hinges were counted as mortalities in both oiled and control frames. The number of living individuals in a frame ranged from 209 to 567 with a mean of 370 (Snedecor, 1956)[132]. A t-test was used to determine the significance of the differences in the percentage of mortalities in test frames and controls. Observations of mortality were restricted by the screening process to *M. balthica* of 5 mm and larger shell length. Mortalities in newly settled spat and other small individuals were not investigated. Sediments were extracted in a Soxhlet apparatus for 48 hours with a one to one mixture of benzene and methanol. The extract was partitioned into hexane, dried, concentrated, and subjected to column chromatography on alumina packed over silica. Soft parts of *M. balthica* were analysed similarly but with the addition of saponification of the extract before column chromatography. A hydrocarbon fraction obtained by this procedure was quantitated gravimetrically. Gas chromatography clearly showed that the increase in hydrocarbons was due to uptake of crude oil.

Results

Significant mortalities did not occur in the test frames subjected to 1.2 μℓ oil cm^{-2}. At the 5.0 μℓ oil cm^{-2} oiling rate significant mortalities were observed two days after the last oiling and remained significant until the last collection (Tables 70 and 72). Data showing the concentration of oil in the sediment and in flesh of *Macoma balthica* at the time of collection are shown in Tables 73 and 74. The highest concentration of oil in sediment which did not produce significant mortality was 530 μgm g^{-1} of dry sediment. The four highest oil concentrations in sediment recorded in Table 74 are the highest found in the course of the experiment. Among these increasing oil concentration is generally reflected in increasing percentage mortality.

The fact that the data in Table 74 does not show a steady decrease in oil concentrations with time requires explanation. We believe that this reflects the fact that each collection in the time series was made from a separate containment frame at a different location in the experimental area. We attribute the scatter in the data to inhomogenity in the sediment with regard to its ability to sorb petroleum. Whatever the source of scatter, the important relationship is the increase in *Macoma balthica* mortality as the concentration of oil in the sediment and in the animal's tissue increases. The data from day 44 further suggests that duration of exposure also plays a role in determining mortality rate.

Discussion

A significant increase in *Macoma balthica* mortality has been shown to accompany an application of crude oil to sediments which approximates the stranding of a light oil slick. We suspect that this relationship between *M. balthica* mortality and the concentration of oil in the top 1 cm of sediment is a result of the animal's deposit feeding habit. Thus, we hypothesize that other deposit feeding species of the genus *Macoma* will have similar potential as indicators of oil pollution. If our hypothesis is correct, *Macoma* may prove to be a valuable indicator, since it has wide

TABLE 72

PERCENTAGE MORTALITIES OF *MACOMA BALTHICA* IN INTERTIDAL TEST FRAMES SUBJECT TO 5.0 µℓ cm^{-2} FOR FIVE DAYS AT PORT VALDEZ, ALASKA

Duration of Exposure (days)	Percentage Mortality Oiled/Control	Significant difference (95% confidence level)
0	/0	-
3	0/0	No
5	0.88/0	No
7	6.4/2.2	Yes
15	1.6/0	Yes
29	11.4/0.2	Yes
44	8.7/0	Yes
60	1.1/0.6	No

TABLE 73

CONCENTRATION OF OIL IN SEDIMENTS EXPRESSED AS μg oil/g OF DRY SEDIMENT, CONCENTRATION OF OIL IN SOFT PARTS OF *MACOMA BALTHICA* EXPRESSED AS μg oil/g OF WET TISSUE, AND PERCENT MORTALITY OF *M. BALTHICA*. EXPERIMENT A (1.2 μg oil cm^{-2}).

Day	Concentration of[a] Hydrocarbon in Sediment	Concentration of[b] Hydrocarbon in *M. balthica*	% Mortality of *M. balthica* exptl/control
0	7.1	14.0	-/0
3	12.0	21.0	0/0
5	33.0	-[c]	0/0
7	76.0	-	0/0.01
9	-	-	0/0
15	22.0	48.0	0/0
29	31.0	22.0	0/0.004
44	5.2	7.0	0/0
60	14.0	7.5	0.03/0

[a] μg oil per gram of dry sediment

[b] μg oil per gram of wet tissue; all animals were depurated for 6 days

[c] dashes indicate data not obtained

TABLE 74

CONCENTRATION OF OIL IN SEDIMENTS EXPRESSED AS μg oil/g OF DRY SEDIMENT, CONCENTRATION OF OIL IN SOFT PARTS OF *MACOMA BALTHICA* EXPRESSED AS μg oil/g OF WET TISSUE, AND PERCENT MORTALITY OF *M. BALTHICA*. EXPERIMENT B (5.0 μg oil cm^{-2}).

Day	Concentration of[a] Hydrocarbon in Sediment	Concentration of[b] Hydrocarbon in *M. balthica*	% Mortality of *M. balthica* exptl/control
0	6.2	14.0	-/0
3	530.0	190.0	0/0
5	420.0	-[c]	0.88/0
7	1720.0	-	6.4/2.2
9	-	-	0.04/0
15	640.0	280.0	1.6/0
29	3890.0	320.0	11.4/0.2
44	760.0	88.0	8.7/0
60	14.0	12.0	1.1/0.6

[a] μg oil per gram of dry sediment

[b] μg oil per gram of wet tissue; all animals were depurated for 6 days

[c] dashes indicate data not obtained

geographic distribution (Shaw *et al.*, 1976)[133]. *Macoma balthica* itself is circum-arctic and occurs in numerous regions of present or contemplated petroleum production and transport.

SECTION XII

GENERAL DISCUSSION

The tidal flat environment of the Port Valdez region displays several laterally varying subfacies. These subfacies are delineated by the presence of unique physicochemical attributes, lithology, and biological communities. The environmental characteristics of a site at the mid-tide (0.0 m) tide level of Island Flats - the most extensive tidal flat region of Port Valdez - have been documented prior and subsequent to the simulation of small-scale, short-term oil spills via addition of Prudhoe Bay crude oil. The sediment studies have demonstrated that, except in local areas supporting dense marine algal populations, all of the tidal flats of Port Valdez have low organic carbon contents in their sediments. This paucity of naturally occurring organic carbon in an area of high potential organic sources is attributable to a ready tidal removal of the organic detrital particles.

There were no detectable changes in the concentrations of several common heavy metals (e.g., Cu, Ni, V, Pb, and Zn) and organic carbon in almost all sediment samples subsequent to the oiling of the tidal flat surfaces. Only the sediment exposed to relatively chronic dosages of Prudhoe Bay crude oil (i.e., 200 ppm oil added 21 times from 19 June through 17 August 1974; Section X), displayed a slight increase in the concentrations of Cu and Zn. In addition, no differences in the concentrations of dissolved H_2S and O_2 were documented in the oiled sediments as compared to the baseline samples.

It is believed that the lack of any significant increase in the heavy metals as well as organic carbon content in almost all oiled sediments is attributable to the swift physical removal of the crude oil from the tidal flat surface by the ebb tide. Bacterial degradation of the crude oil seems an unlikely explanation for the lack of increase in organic carbon. It would seem that the muddy tidal flat sediments, presumably constituted chiefly of primary hydrated phyllosilicates of glacial flour derivative, have limited capacity to sequester hydrocarbons and heavy metals which are either associated with the hydrocarbon or present in an inorganically bound state. This may be an important factor in precluding the immobilization of the Prudhoe crude oil as well as heavy metals either associated or dissociated from the oil in the tidal-flat sediments. As such, it is believed that tidal removal of the oil and the metals is rendered with relative ease.

The sediment studies reported here indicate that in the mid-tide horizon of the Port Valdez tidal flats, insignificant physicochemical perturbations are to be expected in the sedimentary regime as a consequence of small-scale, short-term oil spills. However, a chronic oil spill on a sustained basis may elevate the Cu and Zn concentrations of sediments in the above environment. These conclusions must be considered tentative as they are not based on an exhaustive study nor on a geographically extensive scale, Therefore, any application of the outcome of this study to all the tidal flat areas of Port Valdez or to similar areas elsewhere must be made with extreme caution.

Bacteria are often considered to be the basis of marine sediment food chains. The sediment meiofauna has been shown to feed mainly on bacteria and diatoms attached to sand grains and suspended in the interstitial waters. A substantial portion of the meiofaunal carbon budget is supplied by bacteria, and a crucial factor in the maintenance of the ecosystem appears to be the delivery of soluble organics and dissolved oxygen to the bacteria by movement of water through the sediment. It has been suggested by several studies on sandy shores that drainage through the sediment as well as wave-generated sublittoral pumping may be the dominant mechanism for supplying oxygen and dissolved nutrients to the sediment ecosystem. Additionally, the wave action is necessary for sorting and distribution of the variously sized sediment grains. The lack of wave action in certain areas of Port Valdez would be expected to result in deposition of the silt sediments, compaction from lack of the sorting effect of waves, and increasing impermeability of the sediment. The sediment ecosystem in Port Valdez is, indeed, quite different from those described in the above studies (Section IV). Port Valdez sediments are typically composed of fine glacial silt, and the sediment grains have a mean particle size of from four to sixteen microns with the particle size being uniform to a depth of 5 cm. There appears to be little exchange of fluids between the interstitial water and the overlying tidal waters. The salinity of the interstitial water is always higher than the tidal waters, often by a factor of at least two, even under conditions of heavy rainfall (up to 2 m of rain may occur in Port Valdez during the period from July to October). The Island Flats study site is transected by several streams draining nearby snow fields, and surface runoff of the rainwater is constant and typical. There is no measurable dissolved or precipitated sulfide (except under heavy agal mats), and from 0.1 to 0.3 ppm of iron, with no apparent gradient with depth. The sediment contains less than 0.2% by weight of organic carbon and the interstitial water has a pH of between 7.2 and 7.6, which remains constant to a depth of 16 cm. The low organic content, the lack of sulfide, and the absence of animal remains in the sediment suggest that both endogenous and deposited animal and plant remains are either removed by rapid digestion on the sediment surface or by the action of tidal waters. The lack of sulfide and the presence of measurable amounts of dissolved oxygen indicate an aerobic environment.

Many *in vitro* and *in situ* studies have shown that crude oil is able to provide oxidizable soluble organic nutrients to bacterial populations in marine sand ecosystems. Generally, oil is able to cause an increase in bacterial biomass when added over prolonged periods, but does not appear to permanently affect the size of the population when added only once, as would occur from a spill. Additionally, increased respiratory oxygen uptake has been reported in sand columns enriched with oil, oil dispersants, and with mixtures of oil and dispersant. Using the standard plate count techniques, the only significant change (99.9% confidence levels) observed in the size of the bacterial populations in Port Valdez was in the samples taken from the Old Valdez seepage site and from algal covered sites. The addition of oil to the surface of sediments at concentrations up to 2000 ppm applied on two consecutive days during each low-tide series of one summer, and 200 ppm applied on five consecutive days during each low-tide series of one summer, had no measurable effect on the size of the bacterial population. No attempt was made to differentiate between species or types of bacterial forms. Coincidentally, sediment oxygen uptake rates were similarily unaffected, although when the sediment was supplemented *in vitro*, with glucose or oil, increased oxygen uptake was observed. When the uptake of oxygen was measured two hours after mixing glucose and oil in separate sediment samples, the glucose was observed to cause an immediate increase in the rate of oxygen uptake, but the rate of the oil ammended sediment did not change significantly until after 24 hours. At that time the rate of oxygen consumption surpassed that observed with glucose. No significant seasonal trends were observed in either the plate count data or in the oxygen uptake in unammended sediments, although a Q_{10} (10-20°) of 2.4 and 2.6 was observed for the unsupplemented and supplemented sediments, respectively.

Sulfur-cycle bacteria including sulfate-reducers and photosynthetic sulfide-oxidizers were present in very low numbers, if at all. For example, in a differential plating technique no sulfide producing colonies were observed (out of about 1,000), and only one heavily innoculated enrichment showed positive results. Similarily, the number of photosynthetic sulfur bacteria isolated from similar enrichments were too low to estimate. In contrast, when randomly picked colonies were tested for the ability to produce sulfide on organic medium supplemented with sulfur-containing amino acids, up to 97% of the colonies from control sites and 88% of colonies from oiled sites produced hydrogen sulfide. The low numbers of sulfate reducing bacteria, the high percentage of sulfide producers from organic sources, and the measured low sulfide content of the sediment are consistent with the concept that organic material does not penetrate very deeply into the sediment.

Micro-aquaria, containing sulfate and organic substrate, when innoculated with sediment samples showed normal sulfur cycling activity, although the length of time needed for the model ecosystems to stabilize were considerably longer than those reported for samples from active, sulfide rich sediments. Typically, sulfide was rapidly produced (from added sulfate) as evidenced by blackening the medium. This was followed by a gradual utilization of hydrogen sulfide, probably by photosynthetic and chemoautotrophic bacteria, as shown by a gradual clearing of the sulfide precipitate and appearance of distinct bands of growth. These results, in addition to those showing increased oxygen uptake by *in vitro* enriched sediments, and the increased counts from seepage and algae enriched sediments further support the hypothesis that the low level of biological activity found in these sediment ecosystems is due to the relative impermeability of the sediment and the resulting lack of penetration of dissolved or particulate organic material.

We conclude from our microbiological data that the addition of oil to most Valdez intertidal sediment areas on an intermittent basis will not materially affect the sediment ecosystem in areas with similar physical and biological properties. Surface removal by tidal currents, coupled to digestion in the water column will be a major factor in the biological degradation of accidentally spilled oil. However, more permeable sediments within the Port Valdez area might be expected to show considerable changes from even small, intermittent spills.

A two-year survey of intertidal sediment-dwelling meiofauna and some selected macrofaunal species has demonstrated that the species composition is relatively diverse, and the abundance of organisms as well as general composition of the major taxonomic groups compares with that found in mudflats examined in north temperate regions elsewhere. The fine sediments of Port Valdez presumably preclude the presence of most interstitial forms, and burrowing meiofaunal organisms are the preponderant ones found. Nematodes represent the invertebrate group most common to the sediments of all beaches studied. Over 90% of the meiofaunal organisms were located in the upper three centimeters of the sediment, and this has been explained in terms of the anoxic environment below this depth. No seasonal vertical migration of species was noted during the study period.

Although low salinities occur in waters overlying the sediments during the period of thaw in the spring, sediment salinities remain relatively stable. Meiofaunal copepods do not tolerate the very low salinities of the surface waters, but the much higher salinity of the interstitial waters was always apparently well within the limits of tolerance of the meiofaunal organisms.

Densities of meiofauna generally varied directly with water and sediment temperature. However, high winter densities were noted for the winter of 1972 and 1973, and this is apparently related to the relatively high water temperature recorded for this period.

A general understanding of the fluctuations of meiofauna of Port Valdez is now available. Although the values noted for individual groups of organisms are primarily indications of trends to be expected, it is apparent that this short study has given us a reasonable understanding of density patterns for major groups present in Port Valdez. The winter surge of meiofauna on both the Dayville and Mineral Creek Flats in the winter of 1972 and 1973 indicates that temporary increases of these organisms can occur at the coldest period of the year when primary productivity is at its lowest ebb. The dramatic decrease in meiofaunal numbers immediately after this density peak suggests that these individuals are not important to the general recruitment of meiofauna to the beaches, and do not contribute to the reproductive activities on these beaches later in the year.

Meiofauna has rarely been used as an indicator for oil pollution. Green *et al* (1974)[134] qualitatively monitored meiofauna of a sediment shore after a fuel oil spill, and found that oil did not affect these organisms on any of the beaches investigated. Although it is probable that much of the sediment meiofauna in Port Valdez will also have to be monitored qualitatively if species and density composition on a beach is to be assessed following an oil spill, it is clear that trends documented in our baseline study will make it possible to recognize gross changes in meiofaunal composition with time. However, our field experiments designed to examine the effects of Prudhoe Bay crude oil on sediment-dwelling harpacticoid copepods indicated that at the concentrations used (200, 500, 1000 and 2000 ppm), three species were either not adversely affected or increased in numbers in the presence of oil. It is suggested that these density increases are the result of attraction by the copepods to oil and/or an increase in their reproductive activity. In addition, success in the investigation of the reproductive cycle of one species of harpacticoid copepod, *Harpacticus uniremis*, and preliminary data on reproduction for other harpacticoid species further suggests that this biological parameter might be a useful one for monitoring the effect of oil on beaches in Port Valdez.

In July and August 1975, experiments were carried out to determine the uptake and release of oil by intertidal sediments during a simulated oil spill at Port Valdez and to investigate the effect of oil on a population of the clam *Macoma balthica* resident in that sediment. The experimental oiling regime was intended to approximate a pollution event in which a thin sheen of oil was stranded by each ebbing tide for a few days. Thus, our results probably relate to a minor transient pollution incident but not to chronic or heavy pollution. Following the intentional oilings, the kinds and amounts of hydrocarbons in the sediments and in the tissue of *M. balthica* were monitored. The mortality rate of *M. balthica* in oiled and unoiled plots was also measured. The results of our study of sediments indicate that under the experimental conditions used, petroleum was no longer detectable after two months. Other work elsewhere has shown petroleum to be much more persistent. We conclude that the conditions of oil application and the character of the sediment strongly influence the rate at which the oil is released by the sediment. Thus, extrapolation and generalizations about sediment interactions with petroleum should be made with considerable caution.

Our study of *Macoma balthica* showed that a relationship exists between the concentration of oil in sediment and the mortality of *M. balthica*. We feel that this is a consequence of *M. balthica's* deposit feeding behavior. This result is particularly important because *M. balthica* may be useful as an indicator of oil pollution in intertidal sediments (Shaw *et al.*, 1976)[133] and because *M. balthica*, at least in the area of Prince William Sound, Alaska, is extensively used for food by migrating birds. Thus, there probably exists a two step food chain that transfers petroleum from sediment to birds.

It can be concluded from the experimental sediment, biological and hydrocarbon studies that the surface addition of oil to most of the Valdez intertidal beaches will not materially effect these sediment ecosystems.

It is suggested that tidal action coupled with digestion of oil in the water column will probably be the major factors in removal of oil from the waters of Port Valdez. In contrast, certain areas of the Valdez intertidal zone, such as the well-protected salt marsh in back of the Island Flats study area with its coarser sediments, might be expected to show effects of oil contamination.

SECTION XIII

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APPENDIX A

Analysis of variance of the numbers of each of three species of copepods in control and test (oil-ammended) rings. Collections of 3 July to 15 September 1974. See Section X for experimental methodology and results.

APPENDIX A - TABLE 1

ANALYSIS OF VARIANCE OF THE NUMBERS OF EACH OF THREE SPECIES OF COPEPODS, IN CONTROL AND TEST (OIL-AMMENDED) RINGS COLLECTION OF JULY 3 AND 4, 1974.

C = control, unoiled cores; O = experimental, oiled cores;
df = degrees of freedom; F = F ratio

			Harpacticus uniremis (Type 1)					
Core Numbers	Concen. of Oil (PPM)	Mean No. of Copepods	Source of Variation	df	Mean Square	F	Signif. at 95% Level[a]	Signif. at 99% Level[b]
C 1-20 O 1-20	0 500	3.8 6.4	Sample Means Individ. Means	1 38	70.2 11.8	5.9	Yes	No
C 21-40 O 21-40	0 500	7.6 7.3	Sample Means Individ. Means	1 38	1.2 32.9	0.0	No	No
C 41-60 O 41-60	0 500	5.2 9.6	Sample Means Individ. Means	1 38	198.0 22.2	8.8	Yes	No
C 61-80 O 61-80	0 500	6.7 9.0	Sample Means Individ. Means	1 38	50.6 25.1	2.0	No	No
C 1-20 O 81-100	0 1000	3.8 6.2	Sample Means Individ. Means	1 38	57.6 10.4	5.4	No	No
C 21-40 O 101-120	0 1000	7.6 6.1	Sample Means Individ. Means	1 38	24.0 29.0	0.8	No	No
C 41-60 O 121-140	0 1000	5.2 5.4	Sample Means Individ. Means	1 38	0.4 9.5	0.0	No	No
C 61-80 O 141-160	0 1000	6.7 6.4	Sample Means Individ. Means	1 38	0.9 16.3	0.0	No	No
C 1-20 O 161-180	0 2000	3.8 6.3	Sample Means Individ. Means	1 38	62.5 12.1	5.1	No	No
C 21-40 O 181-200	0 2000	7.6 7.1	Sample Means Individ. Means	1 38	3.0 30.5	0.0	No	No
C 41-60 O 201-220	0 2000	5.2 7.7	Sample Means Individ. Means	1 38	65.0 9.8	6.5	Yes	No
C 61-80 O 221-240	0 2000	6.7 4.3	Sample Means Individ. Means	1 38	57.6 15.5	3.7	No	No

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[a] Significant at 95% level; $F_{\alpha}(2)1,38=5.44$

[b] Significant at 99% level; $F_{\alpha}(2)1,38=8.89$

APPENDIX A - TABLE 1 (Continued)

ANALYSIS OF VARIANCE OF THE NUMBERS OF EACH OF THREE SPECIES OF COPEPODS, IN CONTROL AND TEST (OIL-AMMENDED) RINGS.

			Halectinosoma gothiceps (Type 4)					
Core Numbers	Concen. of Oil (PPM)	Mean No. of Copepods	Source of Variation	df	Mean Square	F	Signif. at 95% Level[a]	Signif. at 99% Level[b]
C 1-20	0	40.5	Sample Means	1	384.4			
O 1-20	500	34.3	Individ. Means	38	379.4	1.0	No	No
C 21-40	0	31.3	Sample Means	1	640.0			
O 21-40	500	39.3	Individ. Means	38	176.2	3.6	No	No
C 41-60	0	38.2	Sample Means	1	4.9			
O 41-60	500	37.5	Individ. Means	38	303.4	0.0	No	No
C 61-80	0	30.5	Sample Means	1	2706.0			
O 61-80	500	46.9	Individ. Means	38	207.3	13.0	Yes	Yes
C 1-20	0	40.5	Sample Means	1	801.0			
O 81-100	1000	31.5	Individ. Means	38	258.8	3.0	No	No
C 21-40	0	31.3	Sample Means	1	126.0			
O 101-120	1000	27.8	Individ. Means	38	135.5	0.9	No	No
C 41-60	0	38.2	Sample Means	1	1575.0			
O 121-140	1000	25.7	Individ. Means	38	186.4	8.4	Yes	No
C 61-80	0	30.5	Sample Means	1	286.2			
O 141-160	1000	25.1	Individ. Means	38	152.9	1.8	No	No
C 1-20	0	40.5	Sample Means	1	497.0			
O 161-180	2000	33.4	Individ. Means	38	244.1	2.0	No	No
C 21-40	0	31.3	Sample Means	1	286.2			
O 181-200	2000	36.7	Individ. Means	38	225.8	1.2	No	No
C 41-60	0	38.2	Sample Means	1	1998.1			
O 201-220	2000	24.1	Individ. Means	38	165.4	12.0	Yes	Yes
C 61-80	0	30.5	Sample Means	1	1113.0			
O 221-240	2000	19.9	Individ. Means	38	120.1	9.2	Yes	Yes

[a] Significant at 95% level; $F_{\alpha}(2)1,38=5.44$

[b] Significant at 99% level; $F_{\alpha}(2)1,38=8.89$

APPENDIX A - TABLE 1 (Continued)

ANALYSIS OF VARIANCE OF THE NUMBERS OF EACH OF THREE SPECIES OF COPEPODS, IN CONTROL AND TEST (OIL-AMMENDED) RINGS.

					Heterolaophonte sp. (Type 10)			
Core Numbers	Concen. of Oil (PPM)	Mean No. of Copepods	Source of Variation	df	Mean Square	F	Signif. at 95% Level[a]	Signif. at 99% Level[b]
C 1-20	0	28.3	Sample Means	1	396.9			
O 1-20	500	34.6	Individ. Means	38	909.8	0.4	No	No
C 21-40	0	31.2	Sample Means	1	164.0			
O 21-40	500	27.1	Individ. Means	38	142.4	1.1	No	No
C 41-60	0	32.6	Sample Means	1	372.1			
O 41-60	500	26.5	Individ. Means	38	136.4	2.7	No	No
C 61-80	0	35.2	Sample Means	1	765.6			
O 61-80	500	26.4	Individ. Means	38	91.1	8.3	Yes	No
C 1-20	0	26.3	Sample Means	1	255.0			
O 81-100	1000	23.2	Individ. Means	38	125.8	2.0	No	No
C 21-40	0	31.2	Sample Means	1	462.4			
O 101-120	1000	24.4	Individ. Means	38	92.7	4.9	No	No
C 41-60	0	32.6	Sample Means	1	225.6			
O 121-160	1000	27.8	Individ. Means	38	145.5	1.5	No	No
C 61-80	0	35.2	Sample Means	1	1368.9			
O 141-160	1000	23.5	Individ. Means	38	77.3	17.6	Yes	Yes
C 1-20	0	28.3	Sample Means	1	87.0			
O 161-180	2000	31.2	Individ. Means	38	140.2	0.6	No	No
C 21-40	0	31.2	Sample Means	1	4.2			
O 181-200	2000	30.5	Individ. Means	38	113.1	0.0	No	No
C 41-60	0	32.6	Sample Means	1	585.2			
O 201-220	2000	24.9	Individ. Means	38	138.0	4.2	No	No
C 61-80	0	35.2	Sample Means	1	1368.9			
O 221-240	2000	23.5	Individ. Means	38	77.3	17.6	Yes	Yes

[a] Significant at 95% level; $F_{\alpha}(2)1,38=5.44$

[b] Significant at 99% level; $F_{\alpha}(2)1,38=8.89$

APPENDIX A - TABLE 2

ANALYSIS OF VARIANCE OF THE NUMBERS OF EACH OF THREE SPECIES OF COPEPODS, IN CONTROL AND TEST (OIL-AMMENDED) RINGS.

			Harpacticus uniremis (Type 1)					
Core Numbers	Concen. of Oil (PPM)	Mean No. of Copepods	Source of Variation	df	Mean Square	F	Signif. at 95% Level[a]	Signif. at 99% Level[b]
C 81-100	0	4.7	Sample Means	1	102.4			
O 241-260	500	7.9	Individ. Means	38	15.1	6.7	Yes	No
C 101-120	0	6.1	Sample Means	1	0.9			
O 261-280	500	5.8	Individ. Means	38	28.3	0.0	No	No
C 121-140	0	3.4	Sample Means	1	60.0			
O 281-300	500	5.9	Individ. Means	38	7.0	8.4	Yes	No
C 141-160	0	3.6	Sample Means	1	54.0			
O 301-320	500	6.7	Individ. Means	38	20.3	2.6	No	No
C 81-100	0	4.7	Sample Means	1	48.4			
O 321-340	1000	6.9	Individ. Means	38	14.9	3.2	No	No
C 101-120	0	6.1	Sample Means	1	30.6			
O 341-360	1000	4.3	Individ. Means	38	23.7	1.2	No	No
C 121-140	0	3.3	Sample Means	1	99.2			
O 361-380	1000	6.5	Individ. Means	38	12.2	8.9	Yes	Yes
C 141-160	0	4.7	Sample Means	1	14.4			
O 381-400	1000	5.9	Individ. Means	38	13.6	1.0	No	No
C 81-100	0	4.7	Sample Means	1	3.6			
O 401-420	2000	5.3	Individ. Means	38	10.3	0.3	No	No
C 101-120	0	6.1	Sample Means	1	0.4			
O 421-440	2000	5.9	Individ. Means	38	22.6	0.0	No	No
C 121-140	0	3.4	Sample Means	1	34.2			
O 441-460	2000	5.3	Individ. Means	38	15.0	2.2	No	No
C 141-160	0	4.7	Sample Means	1	18.2			
O 461-480	2000	6.0	Individ. Means	38	15.1	1.1	No	No

[a] Significant at 95% level; $F_{\alpha}(2)1,38=5.44$

[b] Significant at 99% level; $F_{\alpha}(2)1,38=8.89$

APPENDIX A - TABLE 2 (Continued)

ANALYSIS OF VARIANCE OF THE NUMBERS OF EACH OF THREE SPECIES OF COPEPODS, IN CONTROL AND TEST (OIL-AMMENDED) RINGS.

			Halectinosoma gothiceps (Type 4)					
Core Numbers	Concen. of Oil (PPM)	Mean No. of Copepods	Source of Variation	df	Mean Square	F	Signif. at 95% Level[a]	Signif. at 99% Level[b]
C 81-100	0	48.5	Sample Means	1	180.6			
O 241-260	500	52.7	Individ. Means	38	322.7	0.5	No	No
C 101-120	0	32.7	Sample Means	1	1849.6			
O 261-280	500	46.3	Individ. Means	38	321.6	5.7	Yes	No
C 121-140	0	41.6	Sample Means	1	354.0			
O 281-300	500	47.6	Individ. Means	38	169.2	2.0	No	No
C 141-160	0	20.8	Sample Means	1	6528.0			
O 301-320	500	46.3	Individ. Means	38	185.6	35.1	Yes	Yes
C 81-100	0	48.5	Sample Means	1	75.6			
O 321-340	1000	51.2	Individ. Means	38	375.4	0.2	No	No
C 101-120	0	32.7	Sample Means	1	1768.9			
O 341-360	1000	46.0	Individ. Means	38	190.2	9.2	Yes	Yes
C 121-140	0	41.6	Sample Means	1	9.0			
O 361-380	1000	40.7	Individ. Means	38	229.8	0.0	No	No
C 141-160	0	20.8	Sample Means	1	3045.0			
O 381-400	1000	38.2	Individ. Means	38	123.0	24.7	Yes	Yes
C 81-100	0	48.5	Sample Means	1	180.6			
O 401-420	2000	44.2	Individ. Means	38	153.0	1.1	No	No
C 101-120	0	32.7	Sample Means	1	801.0			
O 421 -440	2000	41.7	Individ. Means	38	121.9	6.5	Yes	No
C 121-140	0	41.6	Sample Means	1	9.0			
O 441-460	2000	40.7	Individ. Means	38	229.8	0.0	No	No
C 141-160	0	20.8	Sample Means	1	0.0			
O 461-480	2000	20.8	Individ. Means	38	199.9	0.0	No	No

[a] Significant at 95% level; $F_{\alpha}(2)1,38=5.44$

[b] Significant at 99% level; $F_{\alpha}(2)1,38=8.89$

APPENDIX A - TABLE 2 (Continued)

ANALYSIS OF VARIANCE OF THE NUMBERS OF EACH OF THREE SPECIES OF COPEPODS, IN CONTROL AND TEST (OIL-AMMENDED) RINGS.

			Heterolaophonte sp. (Type 10)					
Core Numbers	Concen. of Oil (PPM)	Mean No. of Copepods	Source of Variation	df	Mean Square	F	Signif. at 95% Level[a]	Signif. at 99% Level[b]
C 81-100	0	25.6	Sample Means	1	291.6			
O 241-260	500	20.2	Individ. Means	38	67.5	4.3	No	No
C 101-120	0	28.0	Sample Means	1	476.1			
O 261-280	500	21.1	Individ. Means	38	88.3	5.3	No	No
C 121-140	0	25.3	Sample Means	1	672.4			
O 281-300	500	17.1	Individ. Means	38	71.3	9.4	Yes	Yes
C 141-160	0	26.0	Sample Means	1	792.1			
O 301-320	500	17.1	Individ. Means	38	91.0	8.6	Yes	No
C 81-100	0	25.6	Sample Means	1	176.4			
O 321-340	1000	21.4	Individ. Means	38	52.0	3.3	No	No
C 101-120	0	28.0	Sample Means	1	96.0			
O 341-360	1000	24.9	Individ. Means	38	73.1	1.3	No	No
C 121-140	0	25.3	Sample Means	1	22.5			
O 361-380	1000	26.8	Individ. Means	38	118.6	0.1	No	No
C 141-160	0	26.0	Sample Means	1	348.1			
O 381-400	1000	20.1	Individ. Means	38	63.9	5.4	No	No
C 81-100	0	25.6	Sample Means	1	260.1			
O 401-420	2000	20.5	Individ. Means	38	40.9	6.3	Yes	No
C 101-120	0	28.0	Sample Means	1	30.6			
O 421-440	2000	26.2	Individ. Means	38	50.7	0.6	No	No
C 121-140	0	25.3	Sample Means	1	27.2			
O 441-460	2000	23.7	Individ. Means	38	101.4	0.2	No	No
C 141-160	0	26.0	Sample Means	1	67.6			
O 461-480	2000	23.4	Individ. Means	38	69.2	0.9	No	No

[a] Significant at 95% level; $F_\alpha(2)1,38=5.44$

[b] Significant at 99% level; $F_\alpha(2)1,38=8.89$

APPENDIX A - TABLE 3

ANALYSIS OF VARIANCE OF THE NUMBERS OF EACH OF THREE SPECIES OF COPEPODS, IN CONTROL AND TEST (OIL-AMMENDED) RINGS.

COLLECTION OF AUGUST 2, 1974

C = control, unoiled cores; O = experimental, oiled cores;
df = degrees of freedom; F = F ratio.

					Harpacticus uniremis (Type 1)			
Core Numbers	Concen. of Oil (PPM)	Mean No. of Copepods	Source of Variation	df	Mean Square	F	Signif. at 95% Level[a]	Signif. at 99% Level[b]
C 161-180	0	9.6	Sample Means	1	55.2			
O 481-500	500	7.3	Individ. Means	38	20.5	2.6	No	No
C 181-200	0	7.5	Sample Means	1	62.5			
O 501-520	500	10.0	Individ. Means	38	36.3	1.7	No	No
C 201-220	0	9.1	Sample Means	1	0.6			
O 521-540	500	9.3	Individ. Means	38	28.2	0.0	No	No
C 221-240	0	7.6	Sample Means	1	42.0			
O 541-560	500	5.6	Individ. Means	38	27.4	1.5	No	No
C 161-180	0	9.6	Sample Means	1	235.2			
O 561-580	1000	4.8	Individ. Means	38	10.9	21.3	Yes	Yes
C 181-200	0	7.5	Sample Means	1	14.4			
O 581-600	1000	6.3	Individ. Means	38	13.5	1.0	No	No
C 201-220	0	9.1	Sample Means	1	72.9			
O 601-620	1000	6.4	Individ. Means	38	17.4	4.1	No	No
C 221-240	0	7.6	Sample Means	1	14.4			
O 621-640	1000	6.4	Individ. Means	38	21.9	0.6	No	No
C 161-180	0	9.6	Sample Means	1	156.0			
O 641-660	2000	17.0	Individ. Means	38	12.2	12.7	Yes	Yes
C 181-200	0	7.5	Sample Means	1	99.2			
O 661-680	2000	4.4	Individ. Means	38	12.2	8.1	Yes	No
C 201-220	0	9.1	Sample Means	1	184.9			
O 681-700	2000	22.5	Individ. Means	38	26.8	6.8	Yes	No
C 221-240	0	7.6	Sample Means	1	112.2			
O 701-720	2000	4.3	Individ. Means	38	13.5	8.2	Yes	No

[a] Significant at 95% level; $F_{\alpha}(2)1,38=5.44$

[b] Significant at 99% level; $F_{\alpha}(2)1,38=8.89$

APPENDIX A - TABLE 3 (Continued)

ANALYSIS OF VARIANCE OF THE NUMBERS OF EACH OF THREE SPECIES OF COPEPODS, IN CONTROL AND TEST (OIL-AMMENDED) RINGS.

Core Numbers	Concen. of Oil (PPM)	Mean No. of Copepods	Source of Variation	df	Mean Square	F	Signif. at 95% Level[a]	Signif. at 99% Level[b]
			Halectinosoma gothiceps (Type 4)					
C 161-180	0	28.3	Sample Means	1	1030.2			
O 481-500	500	38.5	Individ. Means	38	178.5	5.7	Yes	No
C 181-200	0	31.9	Sample Means	1	32.4			
O 501-520	500	33.7	Individ. Means	38	204.9	0.1	No	No
C 201-220	0	23.3	Sample Means	1	6943.2			
O 521-540	500	49.6	Individ. Means	38	174.4	39.7	Yes	Yes
C 221-240	0	17.4	Sample Means	1	5359.2			
O 541-560	500	40.6	Individ. Means	38	281.6	19.0	Yes	Yes
C 161-180	0	28.3	Sample Means	1	3348.9			
O 561-580	1000	46.6	Individ. Means	38	173.0	19.3	Yes	Yes
C 181-200	0	31.9	Sample Means	1	6350.4			
O 581-600	1000	57.1	Individ. Means	38	127.6	49.7	Yes	Yes
C 201-220	0	23.3	Sample Means	1	9828.2			
O 601-620	1000	54.6	Individ. Means	38	230.7	42.5	Yes	Yes
C 221-240	0	17.4	Sample Means	1	10080.6			
O 621-640	1000	49.2	Individ. Means	38	209.4	48.13	Yes	Yes
C 161-180	0	28.3	Sample Means	1	1199.0			
O 641-660	2000	39.3	Individ. Means	38	167.3	7.1	Yes	No
C 181-200	0	40.9	Sample Means	1	810.0			
O 661-680	2000	31.1	Individ. Means	38	93.0	8.7	Yes	Yes
C 201-220	0	23.3	Sample Means	1	409.6			
O 681-700	2000	29.7	Individ. Means	38	118.3	3.4	No	No
C 221-240	0	17.4	Sample Means	1	1946.0			
O 701-720	2000	31.4	Individ. Means	38	104.9	18.5	Yes	Yes

[a] Significant at 95% level; $F_\alpha(2)1,38=5.44$

[b] Significant at 99% level; $F_\alpha(2)1,38=8.89$

APPENDIX A - TABLE 3 (Continued)

ANALYSIS OF VARIANCE OF THE NUMBERS OF EACH OF THREE SPECIES OF COPEPODS, IN CONTROL AND TEST (OIL-AMMENDED) RINGS.

					Heterolaophonte sp. (Type 10)			
Core Numbers	Concen. of Oil (PPM)	Mean No. of Copepods	Source of Variation	df	Mean Square	F	Signif. at 95% Level[a]	Signif. at 99% Level[b]
C 161-180	0	13.8	Sample Means	1	265.2			
O 481-500	500	18.9	Individ. Means	38	42.4	6.2	Yes	No
C 201-220	0	15.0	Sample Means	1	11.8			
O 521-540	500	19.1	Individ. Means	38	17.4	3.8	No	No
C 221-240	0	11.8	Sample Means	1	319.2			
O 541-560	500	17.4	Individ. Means	38	80.1	3.9	No	No
C 161-180	0	13.8	Sample Means	1	193.6			
O 561-580	1000	18.2	Individ. Means	38	1810.4	4.0	No	No
C 181-200	0	12.0	Sample Means	1	656.1			
O 581-600	1000	20.1	Individ. Means	38	27.6	23.7	Yes	Yes
C 201-220	0	15.0	Sample Means	1	366.0			
O 601-620	1000	21.1	Individ. Means	38	44.6	8.1	Yes	No
C 221-240	0	11.8	Sample Means	1	893.0			
O 621-640	1000	21.2	Individ. Means	38	78.4	11.3	Yes	Yes
C 161-180	0	13.8	Sample Means	1	230.4			
O 641-660	2000	18.6	Individ. Means	38	35.1	6.5	Yes	No
C 181-200	0	12.0	Sample Means	1	384.4			
O 661-680	2000	18.2	Individ. Means	38	32.7	11.7	Yes	Yes
C 201-220	0	15.5	Sample Means	1	15.6			
O 681-700	2000	13.8	Individ. Means	38	29.0	0.5	No	No
C 221-240	0	11.8	Sample Means	1	547.6			
O 701-720	2000	19.2	Individ. Means	38	27.1	20.1	Yes	Yes

[a] Significant at 95% level; $F_{\alpha}(2)1,38=5.44$

[b] Significant at 99% level; $F_{\alpha}(2)1,38=8.89$

APPENDIX A - TABLE 4

ANALYSIS OF VARIANCE OF THE NUMBERS OF EACH OF THREE SPECIES OF COPEPODS, IN CONTROL AND TEST (OIL-AMMENDED) RINGS. COLLECTION OF AUGUST 16, 1974.

C = control, unoiled cores; O = experimental, oiled cores;
df = degrees of freedom; F = F ratio.

					Harpacticus uniremis (Type 1)			
Core Numbers	Concen. of Oil (PPM)	Mean No. of Copepods	Source of Variation	df	Mean Square	F	Signif. at 95% Level[a]	Signif. at 99% Level[b]
C 241-260	0	5.5	Sample Means	1	160.0			
O 721-740	500	9.5	Individ. Means	38	26.5	6.0	Yes	No
C 261-280	0	6.4	Sample Means	1	0.9			
O 741-760	500	17.5	Individ. Means	38	14.8	0.0	No	No
C 281-300	0	10.4	Sample Means	1	0.9			
O 761-780	500	10.1	Individ. Means	38	26.3	0.0	No	No
C 301-320	0	7.3	Sample Means	1	0.0			
O 781-800	500	7.4	Individ. Means	38	11.1	0.0	No	No
C 241-260	0	5.5	Sample Means	1	3.0			
O 801-820	1000	6.1	Individ. Means	38	11.0	0.2	No	No
C 261-280	0	6.4	Sample Means	1	0.0			
O 821-840	1000	6.4	Individ. Means	38	14.0	0.0	No	No
C 281-300	0	10.4	Sample Means	1	75.6			
O 841-860	1000	14.1	Individ. Means	38	21.4	3.5	No	No
C 301-320	0	7.3	Sample Means	1	126.0			
O 861-880	1000	10.9	Individ. Means	38	26.9	4.6	No	No
C 241-260	0	5.5	Sample Means	1	60.0			
O 881-900	2000	3.1	Individ. Means	38	8.3	7.1	Yes	No
C 261-280	0	6.4	Sample Means	1	42.0			
O 901-920	2000	4.3	Individ. Means	38	12.5	3.3	No	No
C 281-300	0	10.4	Sample Means	1	403.2			
O 921-940	2000	4.0	Individ. Means	38	19.4	20.7	Yes	Yes
C 301-320	0	7.3	Sample Means	1	202.5			
O 941-960	2000	2.8	Individ. Means	38	8.0	507.6	Yes	Yes

[a] Significant at 95% level; $F_{\alpha}(2)1,38=5.44$

[b] Significant at 99% level; $F_{\alpha}(2)1,38=8.89$

APPENDIX A - TABLE 4 (Continued)

ANALYSIS OF VARIANCE OF THE NUMBERS OF EACH OF THREE SPECIES OF COPEPODS, IN CONTROL AND TEST (OIL-AMMENDED) RINGS.

			Halectinosoma gothiceps (Type 4)					
Core Numbers	Concen. of Oil (PPM)	Mean No. of Copepods	Source of Variation	df	Mean Square	F	Signif. at 95% Level[a]	Signif. at 99% Level[b]
C 241-260	0	26.6	Sample Means	1	211.6			
O 721-740	500	31.2	Individ. Means	38	112.6	1.8	No	No
C 261-280	0	23.8	Sample Means	1	748.2			
O 741-760	500	32.5	Individ. Means	38	122.9	6.0	Yes	No
C 281-300	0	25.9	Sample Means	1	1537.6			
O 761-780	500	38.3	Individ. Means	38	247.5	6.2	Yes	No
C 301-320	0	26.5	Sample Means	1	57.6			
O 781-800	500	28.9	Individ. Means	38	104.9	0.5	No	No
C 241-260	0	26.6	Sample Means	1	774.4			
O 801-820	1000	35.4	Individ. Means	38	156.5	4.9	No	No
C 261-280	0	23.8	Sample Means	1	1716.1			
O 821-840	1000	36.9	Individ. Means	38	170.7	10.0	Yes	Yes
C 281-300	0	25.9	Sample Means	1	1612.9			
O 841-860	1000	38.6	Individ. Means	38	193.5	8.3	Yes	No
C 301-320	0	26.5	Sample Means	1	6027.0			
O 861-880	1000	51.1	Individ. Means	38	186.6	32.2	Yes	Yes
C 241-260	0	26.6	Sample Means	1	87.0			
O 881-900	2000	23.6	Individ. Means	38	84.6	1.0	No	No
C 261-280	0	23.8	Sample Means	1	235.2			
O 901-920	2000	28.7	Individ. Means	38	147.1	1.5	No	No
C 281-300	0	25.9	Sample Means	1	7.2			
O 921-940	2000	26.7	Individ. Means	38	193.9	0.0	No	No
C 301-320	0	26.5	Sample Means	1	291.6			
O 941-960	2000	31.9	Individ. Means	38	100.7	2.8	No	No

[a] Significant at 95% level; $F_{\alpha}(2)1,38=5.44$

[b] Significant at 99% level; $F_{\alpha}(2)1,38=8.89$

APPENDIX A - TABLE 4 (Continued)

ANALYSIS OF VARIANCE OF THE NUMBERS OF EACH OF THREE SPECIES OF COPEPODS, IN CONTROL AND TEST (OIL-AMMENDED) RINGS.

				Heterolaophonte sp. (Type 10)				
Core Numbers	Concen. of Oil (PPM)	Mean No. of Copepods	Source of Variation	df	Mean Square	F	Signif. at 95% Level[a]	Signif. at 99% Level[b]
C 241-260	0	9.9	Sample Means	1	207.0			
O 721-740	500	14.5	Individ. Means	38	34.0	6.0	Yes	No
C 261-280	0	11.1	Sample Means	1	10.0			
O 741-760	500	12.1	Individ. Means	38	27.5	0.3	No	No
C 281-300	0	11.2	Sample Means	1	216.2			
O 761-780	500	15.9	Individ. Means	38	70.3	3.0	No	No
C 301-320	0	11.3	Sample Means	1	34.2			
O 781-800	500	13.2	Individ. Means	38	29.2	1.1	No	No
C 241-260	0	9.9	Sample Means	1	13.2			
O 801-820	1000	11.1	Individ. Means	38	31.5	0.4	No	No
C 261-280	0	11.1	Sample Means	1	99.2			
O 821-840	1000	14.2	Individ. Means	38	36.1	2.7	No	No
C 281-300	0	11.2	Sample Means	1	84.1			
O 841-860	1000	14.1	Individ. Means	38	50.8	1.6	No	No
C 301-320	0	11.3	Sample Means	1	240.1			
O 861-880	1000	16.2	Individ. Means	38	26.4	9.0	Yes	Yes
C 241-260	0	9.9	Sample Means	1	46.2			
O 881-900	2000	12.1	Individ. Means	38	28.7	1.6	No	No
C 261-280	0	11.1	Sample Means	1	18.2			
O 901-920	2000	12.4	Individ. Means	38	33.2	0.5	No	No
C 281-300	0	11.2	Sample Means	1	4.2			
O 921-940	2000	11.9	Individ. Means	38	46.4	0.0	No	No
C 301-320	0	11.3	Sample Means	1	11.0			
O 941-960	2000	12.4	Individ. Means	38	25.4	0.4	No	No

[a] Significant at 95% level; $F_{\alpha}(2)1,38=5.44$

[b] Significant at 99% level; $F_{\alpha}(2)1,38=8.89$

APPENDIX A - TABLE 5

ANALYSIS OF VARIANCE OF THE NUMBERS OF EACH OF THREE SPECIES OF COPEPODS, IN CONTROL AND TEST (OIL-AMMENDED) RINGS. COLLECTION SEPTEMBER 15, 1974.

C = control, unoiled cores; O = experimental, oiled cores;
df = degrees of freedom; F = F ratio.

			Harpacticus uniremis (Type 1)					
Core Numbers	Concen. of Oil (PPM)	Mean No. of Copepods	Source of Variation	df	Mean Square	F	Signif. at 95% Level[a]	Signif. at 99% Level[b]
C 321-340	0	6.5	Sample Means	1	3.0			
O 961-980	500	6.0	Individ. Means	38	10.8	0.2	No	No
C 341-360	0	3.2	Sample Means	1	348.1			
O 981-1000	500	9.1	Individ. Means	38	21.2	16.4	Yes	Yes
C 361-380	0	5.0	Sample Means	1	220.9			
O 1001-1020	500	9.7	Individ. Means	38	27.6	7.9	Yes	No
C 381-400	0	6.5	Sample Means	1	280.9			
O 1021-1040	500	11.8	Individ. Means	38	30.6	9.1	Yes	Yes
C 321-340	0	6.5	Sample Means	1	3.6			
O 1041-1060	1000	7.1	Individ. Means	38	13.0	0.2	No	No
C 341-360	0	3.2	Sample Means	1	235.2			
O 1061-1080	1000	8.1	Individ. Means	38	11.3	20.7	Yes	Yes
C 361-380	0	5.0	Sample Means	1	55.2			
O 1081-1100	1000	7.3	Individ. Means	38	19.4	2.8	No	No
C 381-400	0	6.5	Sample Means	1	5.6			
O 1101-1120	1000	7.2	Individ. Means	38	24.7	0.2	No	No
C 321-340	0	6.5	Sample Means	1	105.6			
O 1121-1140	2000	9.8	Individ. Means	38	10.5	10.0	Yes	Yes
C 341-360	0	3.2	Sample Means	1	837.2			
O 1141-1160	2000	12.4	Individ. Means	38	36.3	23.0	Yes	Yes
C 361-380	0	5.0	Sample Means	1	286.2			
O 1161-1180	2000	10.3	Individ. Means	38	12.3	23.1	Yes	Yes
C 381-400	0	6.5	Sample Means	1	12.1			
O 1181-1200	2000	7.6	Individ. Means	38	14.9	0.8	No	No

[a] Significant at 95% level; $F_{\alpha}(2)1,38=5.44$

[b] Significant at 99% level; $F_{\alpha}(2)1,38=8.89$

APPENDIX A - TABLE 5 (Continued)

ANALYSIS OF VARIANCE OF THE NUMBERS OF EACH OF THREE SPECIES OF COPEPODS, IN CONTROL AND TEST (OIL-AMMENDED) RINGS.

			Halectinosoma gothiceps (Type 4)					
Core Numbers	Concen. of Oil (PPM)	Mean No. of Copepods	Source of Variation	df	Mean Square	F	Signif. at 95% Level[a]	Signif. at 99% Level[b]
C 321-340	0	22.6	Sample Means	1	270.4			
O 961-980	500	27.8	Individ. Means	38	73.9	3.6	No	No
C 341-360	0	20.0	Sample Means	1	270.4			
O 981-1000	500	25.2	Individ. Means	38	75.5	3.5	No	No
C 361-380	0	22.5	Sample Means	1	980.1			
O 1001-1020	500	32.4	Individ. Means	38	119.7	8.1	Yes	No
C 381-400	0	22.8	Sample Means	1	960.4			
O 1021-1040	500	32.6	Individ. Means	38	170.7	5.6	Yes	No
C 321-340	0	22.6	Sample Means	1	4.9			
O 1041-1060	1000	23.3	Individ. Means	38	49.0	0.0	No	No
C 341-360	0	20.0	Sample Means	1	112.2			
O 1061-1080	1000	23.3	Individ. Means	38	56.3	1.9	No	No
C 361-380	0	22.5	Sample Means	1	108.9			
O 1081-1100	1000	19.2	Individ. Means	38	77.4	1.4	No	No
C 381-400	0	22.8	Sample Means	1	5.6			
O 1101-1120	1000	22.0	Individ. Means	38	91.4	0.0	No	No
C 321-340	0	22.6	Sample Means	1	260.1			
O 1121-1140	2000	27.7	Individ. Means	38	50.9	5.1	No	No
C 341-360	0	20.0	Sample Means	1	403.2			
O 1141-1160	2000	26.3	Individ. Means	38	46.6	8.6	Yes	No
C 361-380	0	22.5	Sample Means	1	0.6			
O 1161-1180	2000	22.8	Individ. Means	38	112.0	0.0	No	No
C 381-400	0	22.8	Sample Means	1	119.0			
O 1181-1200	2000	26.2	Individ. Means	38	116.1	1.0	No	No

[a] Significant at 95% level; $F_{\alpha}(2)1,38=5.44$

[b] Significant at 99% level; $F_{\alpha}(2)1,38=8.89$

APPENDIX A - TABLE 5 (Continued)

ANALYSIS OF VARIANCE OF THE NUMBERS OF EACH OF THREE SPECIES OF COPEPODS, IN CONTROL AND TEST (OIL-AMMENDED) RINGS.

Heterolaophonte sp. (Type 10)

Core Numbers	Concen. of Oil (PPM)	Mean No. of Copepods	Source of Variation	df	Mean Square	F	Signif. at 95% Level[a]	Signif. at 99% Level[b]
C 321-340 O 961-980	0 500	11.5 9.3	Sample Means Individ. Means	1 38	50.6 21.7	2.3	No	No
C 341-360 O 981-1000	0 500	10.1 10.5	Sample Means Individ. Means	1 38	2.0 23.7	0.0	No	No
C 361-380 O 1001-1020	0 500	10.0 8.4	Sample Means Individ. Means	1 38	24.0 24.6	0.9	No	No
C 381-400 O 1021-1040	0 500	10.4 13.6	Sample Means Individ. Means	1 38	102.4 27.8	3.6	No	No
C 321-340 O 1041-1060	0 1000	11.5 11.3	Sample Means Individ. Means	1 38	0.6 16.8	0.0	No	No
C 341-360 O 1061-1080	0 1000	10.1 9.4	Sample Means Individ. Means	1 38	4.9 27.1	0.1	No	No
C 361-380 O 1081-1100	0 1000	10.0 11.4	Sample Means Individ. Means	1 38	19.6 29.3	0.6	No	No
C 381-400 O 1101-1120	0 1000	10.4 10.8	Sample Means Individ. Means	1 38	2.0 20.6	0.0	No	No
C 321-340 O 1121-1140	0 2000	11.5 12.1	Sample Means Individ. Means	1 38	3.0 22.1	0.1	No	No
C 341-360 O 1141-1160	0 2000	10.1 15.7	Sample Means Individ. Means	1 38	319.2 39.9	7.9	Yes	No
C 361-380 O 1161-1180	0 2000	10.0 16.9	Sample Means Individ. Means	1 38	483.0 27.0	17.8	Yes	Yes
C 381-400 O 1181-1200	0 2000	10.4 12.6	Sample Means Individ. Means	1 38	48.4 12.6	3.8	No	No

[a] Significant at 95% level; $F_{\alpha}(2)1,38=5.44$

[b] Significant at 99% level; $F_{\alpha}(2)1,38=8.89$

APPENDIX B

RESPONSE OF THE CLAM, *MACOMA BALTHICA* (LINNAEUS), EXPOSED TO PRUDHOE BAY CRUDE OIL AS UNMIXED OIL, WATER-SOLUBLE FRACTION, AND SEDIMENT-ADSORBED FRACTION IN THE LABORATORY[1]

by

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[1] The laboratory studies on *Macoma balthica* reported in this section were conducted by the National Marine Fisheries Service at the Auke Bay Fisheries Laboratory. Tamra L. Taylor completed the studies with the assistance of personnel of the Physiology-Bioassay Section under the direction of John F. Karinen. Dr. Howard Feder, University of Alaska suggested the research problem, assisted in the design and evaluation of the initial aquarium experiment, and participated in final manuscript preparation.

ABSTRACT

The small clam, *Macoma balthica* (Linnaeus, 1758), occurs throughout the coastal areas of Alaska in the upper 4 to 8 cm of intertidal mudflats. Because it is both a deposit and suspension feeder, *M. balthica* is potentially susceptible to oil slicks layered on the mud and to water-soluble or sediment-adsorbed fractions of crude oil. Settling of unmixed Prudhoe Bay crude oil on the mud during five simulated low tides (2 to 3 h each) had negligible effects on buried adult *M. balthica* observed for 2 months. However, the water-soluble fraction (WSF) of Prudhoe Bay crude oil had an effect on *M. balthica* both in static and flow-through bioassays. In static bioassays, WSF's prepared from a 1% oil-water mixture in concentrations of 11% and 87% of the saturated WSF, (naphthalene equivalents, 0.036 and 0.331 ppm respectively) caused many buried clams to come to the surface. The greatest response occurred within 3 days at the high concentration (0.331 ppm) and 9 days at the low concentration (0.036 ppm). Although at the lower concentration the response took longer to occur, more clams came to the surface. In flow-through bioassays WSF's prepared from 1% oil-water mixtures in concentrations ranging from 7 to 80% of the saturated WSF (naphthalene equivalents, 0.019 to 0.302 ppm) inhibited burrowing of some unburied clams and caused other buried clams to come to the surface. The ECm is 0.233 and 0.222 ppm naphthalene equivalents respectively for ability of unburied clams to burrow into the sediment within 60 and 170 min from start to exposure. The ECm is 0.361 ppm naphthalene equivalents for response of buried clams to move to the surface within 3 days from start of exposure. Oil adsorbed on sediment and allowed to settle over buried *M. balthica* also stimulated movement to the surface. The proportion of clams that moved to the surface increased as the depth of oil-contaminated sediment increased. We calculated that under conditions of our laboratory experiment it would take a layer of oil-contaminated sediment 0.668 cm deep to cause 50% of the buried clams to move to the surface within 1 day. In our tests many of the clams recovered from exposure but in nature they might have fallen to predators or adverse environmental conditions. Data on the response of *M. balthica* to oil can

be used in the evaluation of the organism as an indicator of the effect of oil in the sediment environment.

INTRODUCTION

When the trans-Alaska oil pipeline is completed, the port of Valdez in Prince William Sound will become the staging area for loading crude oil into tankers for transport to refineries. It is during oil transporting activities here that the highest risk of oil contamination will occur.

Several scientists have been involved in projects near the terminal site which are aimed at determining how such activities might affect the marine resources in the area. Since the fall of 1968, Dr. Richard T. Myren and the Environmental Impact Investigation at ABFL (Auke Bay Fisheries Laboratory) have been gathering quantitative data on the intertidal communities near Valdez (unpublished). John Karinen, Dr. Stanley Rice, and the Physiology-Bioassay Section at ABFL have run a series of experiments on key marine species to determine the effects of oil under varying conditions. Dr. Howard M. Feder, Institute of Marine Science, University of Alaska, Fairbanks, has conducted a project funded by the Environmental Protection Agency to determine the effects of oil on the sediment environment of Port Valdez and Galena Bay (Feder, this report).

Emphasis in the studies by Myren and Feder, has been on intertidal organisms of the sediment environment, especially on the tiny clam, *Macoma balthica* (Figure 1), which is abundant on the low-gradient mudflat at Dayville, 1 mile east of the tanker terminal in Valdez and on other suitable mudflats throughout Alaska. *Macoma balthica* buries itself in soft sediments just below the surface and reaches out with separate siphons to feed and respire at the surface (Brafield 1961, 81-82[1]; Rasmussen, 1973, 308-309[2]). Since it feeds on both deposited and suspended matter, it is likely to be a good indicator of the effect of oil in a sediment environment.

This paper is a summary of the laboratory work done with *M. balthica* in 1975 at ABFL. The objective was to measure the response of the clam to exposure to Prudhoe Bay crude oil.

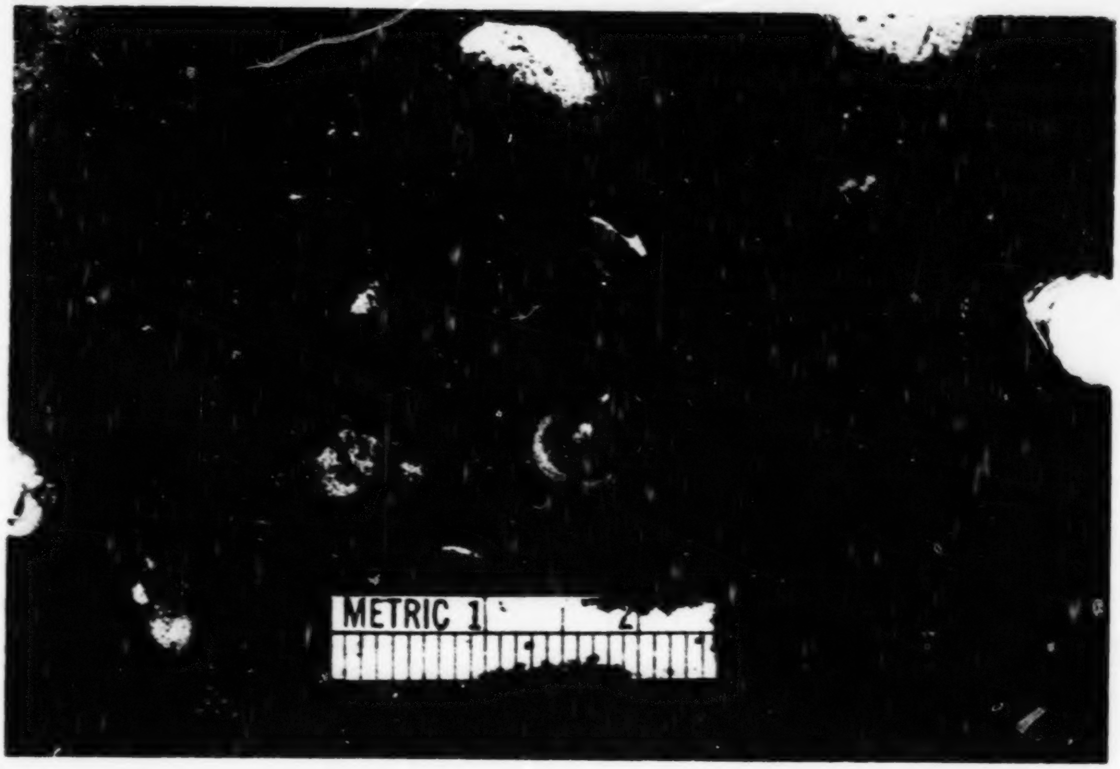


Figure 1. Photograph of the experimental animal, *Macoma balthica*. Note the separate siphons. The incurrent siphon is the longer and more frequently seen of the two; the excurrent siphon is shorter and normally held beneath the sediment surface.

The effect of oil on the clams was tested three ways, which involved three methods of mixing Prudhoe Bay crude oil into the environment of *M. balthica*. Experiment 1, representing a low level of mixing energy, was designed to simulate a crude oil spill stranded on a tideflat under calm conditions. Experiment 2, representing a moderate level of mixing energy, consisted of exposing clams to water-soluble fractions (WSF) of oil. Experiment 3, representing a high level of mixing energy, consisted of exposing clams to oil-contaminated sediments. Mortality and behavior were observed and recorded in all three experiments; burrowing was the primary response observed in the second and third experiments.

Organization of the report is as follows: methods common to all experiments are presented first, then each type of experiment is described separately, followed by a general discussion and evaluation of *M. balthica* as a bioassay organism and baseline indicator of the effect of oil in the sediment environment.

METHODS COMMON TO ALL EXPERIMENTS

The *Macoma balthica* and marine mud used in the experiments were collected from a mudflat 183 m south of the public launching ramp at Amalga Harbor near Eagle River northwest of Juneau. The area has had only limited use and is regarded as relatively free of oil contamination.

Techniques of chemical analyses of the water and tissue samples were the same for all experiments. Water samples were analyzed for hydrocarbons by IR (infrared) and UV (ultraviolet) spectrophotometric procedures. Infrared water analysis to determine paraffinic hydrocarbons followed the technique of Gruenfeld (1973)[3] using tricholorotrifluoroethane (Freon 113) as a solvent and reading at a wave number of 2930 cm^{-1}. This method detects paraffins in concentrations greater than 0.25 ppm (Loren Cheatham, personal communication). Water analysis was also accomplished by an ultraviolet spectrophotometric technique using hexane as the extracting solvent and estimating naphthalene concentration by reading OD (optical density) at 221 nm (Neff and Anderson, 1975, p. 122-128)[4]. This method is accurate for concentrations greater than 0.005 ppm equivalents of naphthalene

(Loren Cheatham, personal communication). Efficiency of naphthalene extraction ranged from 91 to 95%. Concentrations were expressed as naphthalene equivalents, relating them to a naphthalene standard. Oil contamination in clam tissues was measured with UV by a similar method but modified to include tissue digestion with papain (Neff and Anderson, 1975, p. 122-128)[4].

UNMIXED CRUDE OIL SPILL - EXPERIMENT 1

This experiment is similar to an earlier experiment conducted in Port Valdez in which tidal stranding of an oil slick on a mudflat was simulated (Shaw *et al.*, 1976)[5]. Shaw *et al.* put crude oil in aluminum frames (topless and bottomless boxes) placed on a Valdez mudflat, and sampled the enclosed *M. balthica* regularly to determine how many were alive and how much hydrocarbon they had in their tissues. The hydrocarbon content of living clams and percentage of empty valves indicated that the oil had killed *M. balthica*, but more information regarding the response of the clams to the oil was needed. We designed laboratory experiments with provisions for gradual draining and refilling of tanks to simulate the tidal ebb and flow on a mudflat. We determined survival, behavior, and uptake of oil by *M. balthica*.

Apparatus and Experimental Procedure

Our experiment was conducted in four rectangular tanks (10,000 cm^2 each). The tanks were constructed of marine plywood painted with two coats of Woolsey Caulux marine paint and the seams sealed with silicone caulk. Six centimeters of mud was placed on the bottom of each tank except in the areas of the inflow and outflow, which were kept clear of mud by wooden partitions flush with the mud surface (Figure 2). The tanks were inclined at a slight angle (5°) to allow water drainage.

The mud used in the experiment was collected in three steps designed to preserve natural conditions as much as possible. First, an area the size of the tanks was marked on the mudflat. Next, the top 3 cm of mud was removed from the area and put into buckets. Last, the next 3 cm of

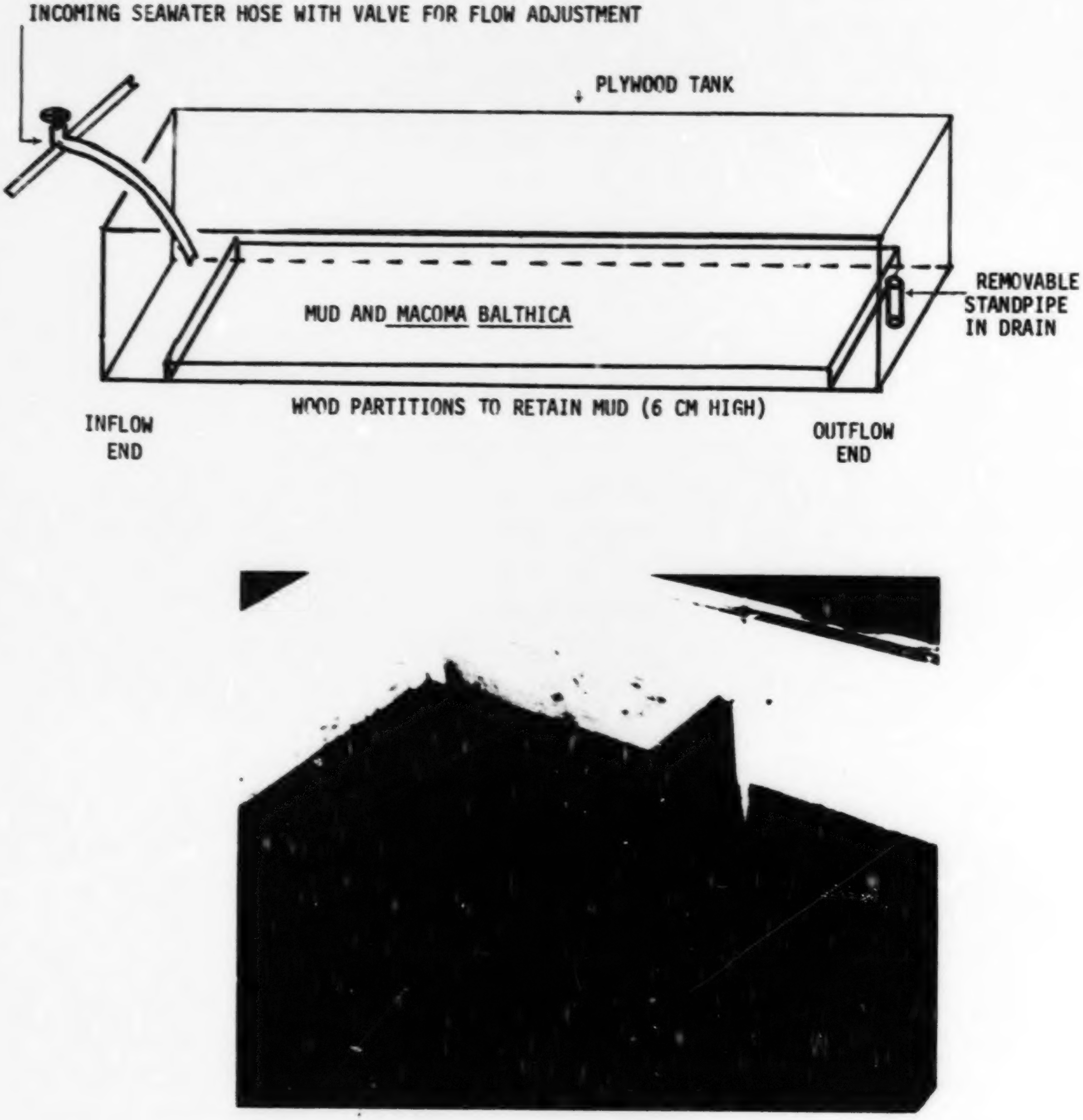

INCOMING SEAWATER HOSE WITH VALVE FOR FLOW ADJUSTMENT
PLYWOOD TANK
MUD AND MACOMA BALTHICA
REMOVABLE STANDPIPE IN DRAIN
WOOD PARTITIONS TO RETAIN MUD (6 CM HIGH)
INFLOW END
OUTFLOW END

Figure 2. Diagram and photograph of outflow tank used in the simulated oil spill. Note the mud (6 cm) layer centered in the bottom of the tank held by the wood portions, with the water flowing over the mud and draining via the standpipe in the drain. Water depth over the mud was approximately 7 cm.

mud was removed and held separately. The mud was not screened nor were any organisms removed from it. The two layers were placed in their original order in the tanks and leveled. The mud contained many *M. balthica* and other organisms, especially the polychaete worm, *Arenicola* sp. Several hundred *M. balthica* were later added so that each tank contained approximately one clam to every 5 cm^2 or about 2000 clams - a density comparable to that found in Port Valdez (Feder and Myren, unpublished data).

Fresh seawater from Auke Bay flowed continually into the tanks and was maintained 13 cm deep over the mud by a removable standpipe in the drain. To simulate a low tide the standpipes were removed, the water turned off and the tanks allowed to drain. The water level fell at the rate of 0.1 cm min^{-1}. The mud was exposed for 2 to 4 hrs and then the stand-pipes were replaced and the tanks refilled with a gentle flow of water (1.2 ℓ min^{-1}), which did not disturb any sediment. The water was calm and clear throughout the experiment. Water temperatures gradually increased during the course of the experiment and ranged from 7°C in May to a maximum of 12°C in late summer.

Description of Simulated Oil Spill

The experimental set-up was put into operation on 1 May, 1975 - four weeks before the first exposure to oil to allow time for the clams to become acclimated to the apparatus. The first oil was added on 27 May and continued daily for 5 successive days. Three tanks were treated with oil, and the fourth untreated tank was maintained as a control. Three doses of oil (1.2, 2.4, and 5 μl cm^{-2} day^{-1}) were added as the "tide" was falling when the water was about 5 cm deep. The oil was gently poured onto the water and it spread unevenly on the surface. As the water receded the oil settled unevenly on the mud where it remained during low tide. As the water returned on the incoming tide, it lifted the oil from the mud and carried it out through the overflow. A small amount of oil remained on the sides of the tanks, making visible sheens for a few days during subsequent tide manipulations. There were no visible signs that oil had adhered to the sediment surface or had been incorporated into the sediments.

Sampling Method

The effect of the oil on *Macoma balthica* was measured in two ways: (1) by counting live and dead clams, and (2) by measuring the amount of naphthalene in clam tissues. In addition, water analyses were conducted to determine oil content in the water.

Several pieces of apparatus were used to obtain samples. To collect clams, a hollow drill (10 cm inside diameter and beveled at the end) was used to cut mud. The drill was removed and a glass cylinder (6 cm high by 10 cm inside diameter) was twisted into the space left by the drill and sediment spooned out from inside the cylinder. The cylinders were left in place for the duration of the experiment to prevent mud from caving in and changing the water flow patterns.

The live and dead clams were counted and tissue samples taken beginning 2 days after the oil exposure ended. Three replicate samples of clams were taken from each tank once a week for 4 weeks; the tanks were visually monitored for 2 months longer. Water samples were collected from each tank once a day during the oil additions and once a week thereafter for 4 weeks.

The samples were obtained by washing the mud from a 160 cm^2 area (two adjacent glass spacers) through a 1.68 mm screen. Live and dead clams were then segregated from the samples. Clams were considered dead from oil exposure if they were gaping and contained tissue or if they contained no tissue but the valves were intact and the hinge elastic. The live clams were counted and placed in running seawater for 24 hrs to clear their digestive tracts. They were then frozen to await tissue analysis. Two grams of whole clams (wet weight) were used in tissue analyses.

Results and Discussion

No significant mortality of control or exposed clams occurred during the two-month period after exposure to oil. The only indication that the exposed clams experienced any stress was evidenced by reduced siphon activity noticed during the time the oil slicks were on the mud. The quantity of oil in the water and naphthalene in the clam tissues was below the detection limits of our methods. However, water samples were collected after most of the water had drained and what was left was slowly percolating through the mud under the end board into the effluent end drain. Since this water was essentially filtered through the mud, any small amount of oil in the water may have been adsorbed as the water passed through the sediment. No sediment analyses were done to verify this, however.

Our results with respect to clam mortality and accumulation of hydrocarbons within the clams are contrary to the results of a field application of oil reported by Shaw *et al.* (1976)[5]. In our experiment oil did not measurably affect the clams, but Shaw *et al.* found significant mortality at the oiling rate of 5 μl oil cm^{-2}.

Differences in the behavior of oil under field conditions versus our aquarium situation may help to explain the different results. In contrast to what occurs in a field situation, virtually no mixing energy was applied to the oil/water/sediment mixtures in the aquaria. Therefore, one would expect a minimum amount of oil to dissolve into the water phase. A second difference noted in the aquaria which contrasts to a field situation was that because of the slight incline of the tanks, most of the water drained slowly across the surface of the sediment rather than moving through it. Only a small amount of the water percolated through the sediment and under the endboards as the water level in the outflow buffer zone dropped below the sediment surface. Movement of water under the endboards was restricted enough that all of the water did not drain completely from the sediment surface and, therefore, the oil simply settled on the elevated portions and rested on a thin layer of water in the depressions of the sediment surface. Close contact of the oil with the sediment was not uniformly achieved in the aquaria.

The discrepancy between our experiment and that of Shaw *et al.* (1976)[5] is attributed to the fact that virtually no mixing energy was applied to our system; thus, little of the oil was dissolved in the water or adsorbed to the sediments. Analysis of oil in the sediment is needed to verify the latter point, but lack of clam response supports the idea that little or no oil remained in the sediment of our aquaria. Although Shaw *et al.* (1976)[5] did not attempt to quantify mixing energy on the Valdez mudflat during their tests, calm weather prevailed (Feder, personal communication). However, the water in that area carries a heavy sediment load (R. Myren and N. Calvin, personal communication; Section IV of this report) which would have mixed with the oil even during normal tidal and surf action, and would have resulted in transport of the adsorbed oil to the sediment surface. A study by Clark and Finley (1975)[6] gives evidence that direct contact of *Mytilus edulis* with oil causes higher mortality and greater uptake of hydrocarbons than contact with the dissolved fractions.

ACUTE BIOASSAY WITH WATER-SOLUBLE FRACTION - EXPERIMENT 2

Experiments with the WSF and *Macoma balthica* were conducted to measure the effect of dissolved oil on the clams. The response of the clams to the Water Soluble Fractions (WSF) was measured in two ways. First, clams already buried in sediment were exposed to WSF and observed for burrowing activity. Second, clams were placed on top of the sediment and observed as they burrowed. We had two basic types of experimental design with our WSF tests. The first was a static situation in which water temperature and oxygen content were not controlled but were essentially the same for control and exposed clams within tests. The second type of design was a flow-through system where recycled seawater flowed continually, was aerated, and was cooled to a constant temperature to reduce experimental variables. WSF for use in exposures were always prepared in the same manner.

Preparation of the WSF for Use in Exposures

One-percent Prudhoe Bay crude oil in seawater (1 ℓ oil:100 ℓ seawater) was mixed slowly and nonviolently at about 200 R min^{-1} for 20 hrs at ambient water temperatures (10° to 12°C). The mixture was allowed to separate for 20 hrs before the virtually saturated WSF was siphoned from below the slick (Anderson *et al.*, 1974, p. 79)[7]. Since the naphthalene equivalents of the WSF vary from mix to mix, we analyzed the initial mixture using the ultraviolet spectrophotometric technique and diluted it with seawater to concentrations that correspond to percentages of saturated solution (designated 100% solution) containing 0.379 naphthalene equivalents. After the dilutions were made the water was analyzed by IR and UV to verify the concentrations to which the clams were actually exposed.

Design of Static Water System Experiment

Clam exposure in the static water system experiment which tested the response of buried clams to WSF's was conducted in two stainless steel trays (26 cm wide by 40 cm long by 3 cm deep) completely filled with screened mud and submerged in a larger seawater tank (160 cm long by 37 cm wide by 8 cm deep). Water temperature was 8°C at the time of its addition and gradually warmed to a maximum of 18°C. No attempt was made to circulate or aerate the water during exposure, but it was oxygenated at the time of introduction.

There was a seawater control and two WSF dose levels in the experiment. The sample size in each case was 400 initially buried clams. The number used to identify the strength of WSF dose is the average of the ppm of naphthalene equivalents measured on day 0 and day 2 when the water in the tanks was changed. The average for the lower dose is 0.036 ppm and for the higher dose is 0.331 ppm, which is 11.7% and 87% respectively of the 100% WSF containing 0.379 ppm naphthalene equivalents. Concentrations of n-paraffins determined by IR for these same doses were 1.24 and 7.76 ppm.

Design of Flow-Through Water System Experiment

The set-up for the flow-through water system experiment which tested the response of both buried and unburied clams to WSF's was somewhat more elaborate than the static water system experiment because it was designed to accommodate greater water capacity, continued water circulation, aeration, and cooling. Each exposure was conducted in a glass tray (25 cm wide by 45 cm long by 3 cm deep) completely filled with screened mud and submerged in a seawater tank (37 cm wide by 53 cm long by 8 cm deep) similar to the trays and tanks used in the static system test. In addition, there was a separate water-holding tank in association with each seawater tank. The holding tank was filled with 100 ℓ of seawater or WSF which was pumped at the rate of 1.2 ℓ min^{-1} via a submersible pump into the tank containing the clam trays which overflowed through a standpipe into a drain tube leading back into the holding tank. Water aeration occurred at this point. Each holding tank was equipped with a cooling coil which kept the water temperature between 7° and 9°C.

A seawater control and five WSF dose levels were used in this experiment. The sample size in each case was 200 initially buried clams and 40 initially unburied clams. The number used to identify the strength of WSF dose was the average of the naphthalene equivalents in ppm measured on days 0, 2, and 4 when the water in the tanks was changed. The average was 0.019, 0.036, 01081, 0.160, and 0.302 ppm which is 7.5%, 11.6%, 23%, 44%, and 80% respectively of a 100% WSF containing 0.379 ppm naphthalene equivalents. Concentrations of n-paraffins in these doses as measured by IR were 0.378, 1.040, 1.661, 2.480, and 5.809 ppm.

Experimental Methods

The method for measuring response of buried clams to WSF's was different from the method for unburied clams. To test the response of buried clams, trays of mud were held in plain seawater and seeded with *M. balthica* which buried themselves prior to later introduction of WSF's into the same tanks. To test the response of unburied clams, marked clams were held in similar mud trays in fresh seawater separate from the experimental tanks until just before their exposure. At that time the clams were gently screened out of the mud and moved to the surface of mud trays in WSF exposure and control tanks. Time of response for both exposures was measured from the time that oil exposure started.

Doses of the WSF were replaced at various intervals within the experiments in an attempt to compensate for the natural loss of the aromatics (mostly from bacterial growth or volatility) in the WSF over the time period of the experiment. There is evidence that after 48 h the loss is rapid, and varies from one dose to another even under the same conditions (Jeffrey W. Short, personal communication).

The static water system experiment began 6 October 1975, and lasted 11 days. The water-changing schedule in the experiment was as follows:

(1) To start the exposure the plain seawater was drained from the tanks and refilled with 50 ℓ of WSF dose for the exposures and seawater for the control. This water was left in the tanks 48 hrs. (2) At 48 hours the water was drained from the tanks and the exposure tanks were refilled with the same amounts of newly prepared WSF's of the same approximate concentration; the control tank was refilled with seawater. This water was left in the tanks 144 hrs. (3) At 192 hrs, the water was drained from the tanks, and they were all refilled with seawater. This water was left in the tanks for 3 days to constitute the recovery period.

The flow-through water system experiment began 10 November 1975, and lasted 10 days. The water-changing schedule was as follows: (1) To start the exposure the plain seawater was drained from the tanks and the holding tanks refilled with 100 ℓ of WSF dose for the exposures and clean seawater for the control. This water was left in the tanks 48 hrs. (2) At the 48 hrs the water was drained from the tanks and the exposure holding tanks refilled with the same amounts of newly prepared WSF of the same approximate oil concentration as was initially applied; the control holding tank was refilled with seawater. This water was left 48 hours. (3) At the 96 hours step 2 was repeated. This water was left for the duration of the 10-day period.

In addition to testing the response of buried clams to WSF's this experiment included provisions for testing the response of unburied clams to WSF's. The marked clams for this test were placed on the surface of the mud immediately after the introduction of the first dose of WSF. Response was defined as clams burying themselves.

Water analyses by UV and IR techniques were conducted at each WSF dose change to verify the actual dose applied. Water samples were taken from each tank within 10 min of the dose change to obtain data of hydrocarbon content at its highest concentration.

Responses to WSF's are recorded in numbers dead and unburied clams. A dead clam was defined as a clam that was gaping and did not close in response to probing. Dead clams were removed from the exposures at least every other day. Unburied clams were counted as a half if they were partly visible yet vertical in position and partly buried and as a whole if they were lying flat on the surface and totally visible.

In the static water system experiment counts of clams that had responded by burrowing to the surface or dying were made on days 1, 2, 3, 8, 9, 10, and 11.

In the flow-through water system experiment, initially unburied clams were counted for number still at the surface at 10 min intervals from the time of introduction through 170 min, then daily for the remainder of the 10-day experimental period. Counts of initially buried clams that had responded by burrowing to the surface were made daily throughout the 10-day experimental period.

Response statistics were analyzed by a computerized probit analysis program (Finney, 1971)[8]. Results of the initially unburied clam test are expressed as the calculated dose (naphthalene equivalents) at which 50% of the clams will fail to burrow within a specified period of time (ECm) together with the 95% confidence interval of that dose level. In addition, the slope function predicted by the probit analysis program is used to calculate the dose (naphthalene equivalents) with a 95% confidence interval at which the burrowing rates of 10% of exposed clams would be significantly reduced from the normal rate of control clams at 60 min. Results of the initially buried clam tests are expressed as the calculated dose (naphthalene equivalents) at which 50% of the clams will come to the surface (ECm) within a specified period of time together with the 95% confidence interval of that dose level. The data were adjusted through Abbott's formula (Finney, 1971, p. 125)[8] to correct for partial response from the control clams.

Results and Discussion of WSF Exposures

The major observation in the experiments testing the response of initially buried clams to WSF's was that it caused some of the clams to come out of the sediment.

The data from the static water system test indicate that at an average concentration of 0.331 ppm naphthalene equivalents (87% of saturated WSF) the greatest response occurs within 72 hrs and involves 35% of the individuals (Figure 3c). At an average concentration of 0.036 ppm naphthalene

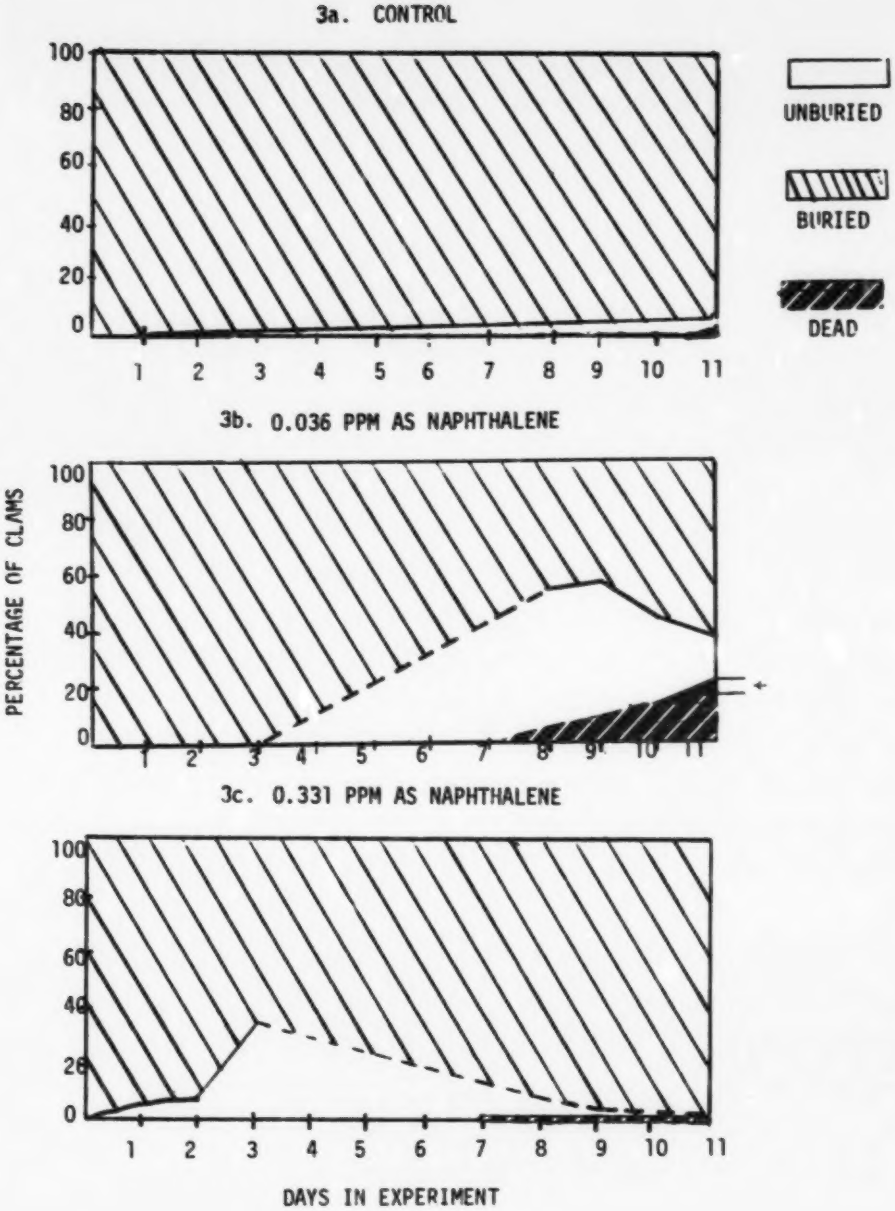


Figure 3. Results of static water system WSF experiment. Each graph represents the clams in one exposure or control. The experiment was 11 days long. The graphs are plotted so that the percentage of clams buried, unburied, or dead are accounted for. Observations were made on days 1, 2, 3, 8, 9, 10, and 11. The dotted line between days 3 and 8 is connecting known point 3 to known point 8 and is not necessarily representative of how many clams were unburied. The arrow in Fig. 3b indicates the area of solid shading that represents the percentage of dead clams not visible at the surface. Control clams made virtually no response.

equivalents (11% of the saturated WSF) the greatest response is delayed to 9 days and involves 57% of the individuals (Fig. 3b). In contrast to the oil exposed clams, 98% of the control clams remain buried during the 11-day monitoring period (Figure 3a). The calculated dose (ppm of naphthalene equivalents) at which 50% of the clams would respond by burrowing to the surface within 3 days under static water system conditions (ECm) is 0.436, with 95% confidence intervals of 0.484 and 0.392.

The data from the flow-through water system test show response proportional to dose clearly for the higher doses (Figure 4). The control clams remain 100% buried throughout the exposure while all of the lower doses show some response. The calculated dose in naphthalene equivalents at which 50% of the clams would respond by burrowing to the surface within 3 days under flow-through water system conditions (ECm) is 0.367, with 95% confidence intervals of 0.411 and 0.317. Under the same conditions the ECm for response within 5 days is 0.323, with 95% confidence intervals of 0.363 and 0.288.

Death as a result of exposure involved 22% of the clams exposed to 11% WSF in the static water system test (Figure 3b). Surprisingly, few of the clams exposed to the higher dose had died at the end of the 11-day observation period. The reason for this unproportional response is not clear; one possibility is that components of the WSF enhanced the growth of bacteria, which may be pathogens to the clams. Higher concentrations of WSF might inhibit such bacterial growth. Another possibility is that various oil doses in connection with enhanced growth of microrganisms may also differentially affect aeration of the sediment and thereby cause toxic conditions to develop. Apparently no such toxic conditions developed with the flow-through water system experiment since there were no actual deaths at any dose. Stegeman and Teal (1973, p. 39)[9] have data for oysters which suggest that for concentrations up to 450 μg hydrocarbon l^{-1} there is a direct relationship between the hydrocarbon concentration in the water and uptake rate, while at higher concentrations the rate of uptake falls. The oysters remained tightly closed when exposed to 900 μg hydrocarbon l^{-1}; thus, they concluded the observed drop in uptake rate at that concentration was probably the result of the oysters avoiding contact

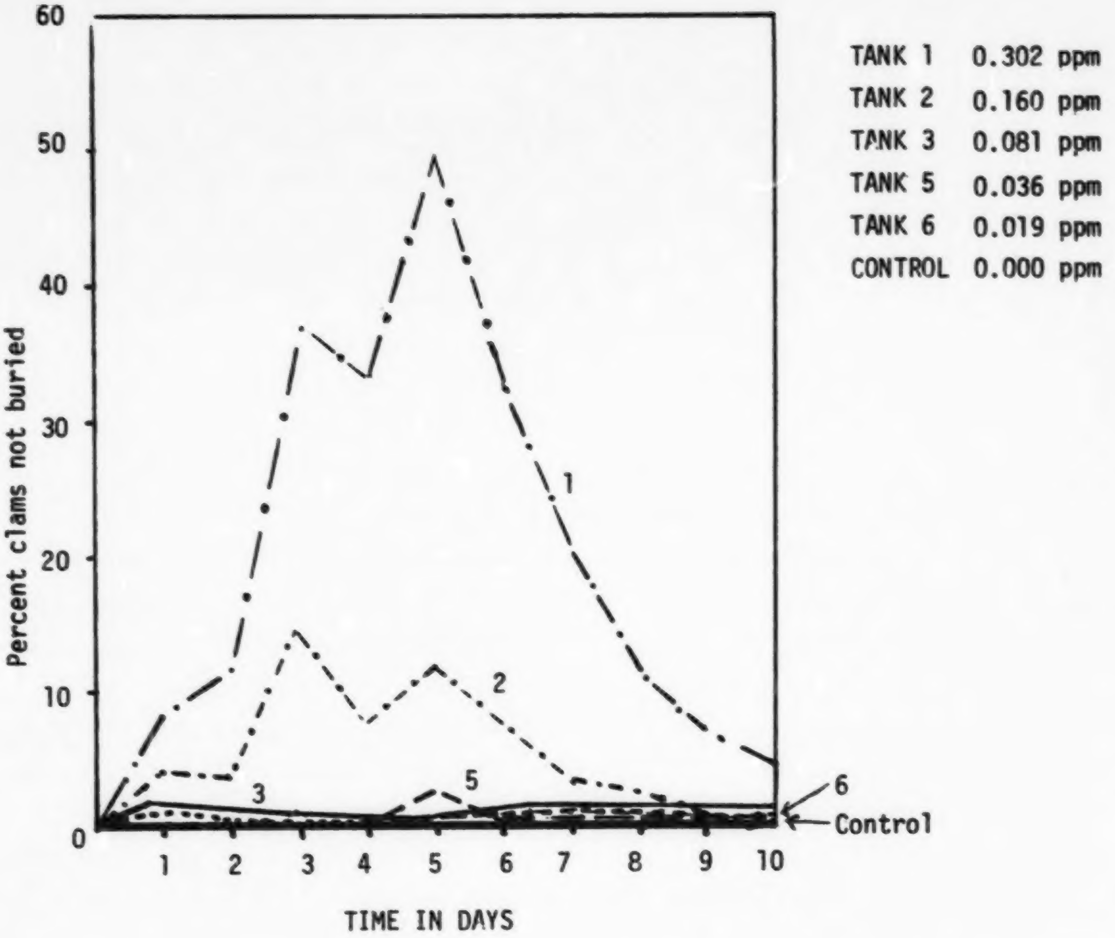


Figure 4. Response of buried *M. balthica* to exposure to WSF in flow-through water system type set-up. The control clams made 0 response throughout. The percentage of clams that responded by coming to the surface is graphed; the area above each line would correspond to the percentage of clams still buried at any time. Concentrations of oil in WSF is expressed as equivalents of naphthalene.

with the oil. It is possible that our high dose of WSF caused the clams to "close up" and isolate themselves from toxins.

The major observation in the flow-through system experiment testing the burrowing response of initially unburied clams to the WSF was that it inhibited the rate of burrowing of some clams. Burrowing rate decreased in proportion to WSF concentration for the higher two doses (Figure 5). There was a decrease at the lower concentrations, although it was not clearly in proportion to dose. The calculated dose (naphthalene equivalents) at which the rate of burrowing of 10% of exposed clams would be significantly reduced from the rate of the control clams at 60 min is 0.044, with 95% confidence intervals of 0.088 and 0.010. The calculated dose at which 50% of the initially unburied clams will fail to burrow within 60 min (ECm) is 0.234, with 95% confidence intervals of 0.310 and 0.175. At the end of the observation period (170 min) the calculated dose at which 50% of the initially unburied clams will fail to burrow (ECm) is 0.222, with 95% confidence intervals of 0.272 and 0.181.

By day 7 in the experiment, at least 97% of all the clams in all the doses were buried. None died within the 10-day period.

In both static and flow-through water system experiments with initially unburied clams, the clams show trends of recovering from exposure and reburying themselves (Figures 3 and 4). We attribute this recovery to loss of toxicants by the WSF and relief from stress for the clams. Recovery occurred without transfer into clean seawater except in the case of the 11% concentration in the static water system test where response was delayed. The depression in the curves at day 4 of the flow-through test (Figure 4) is related to the decrease in potency of the WSF concentration prior to replenishment of a fresh dose of the WSF later that same day.

OIL-CONTAMINATED SEDIMENT TEST - EXPERIMENT 3

The intertidal zone receives energy from wind, waves, and tidal action, and surface sediments and detritus are raised and held in suspension. If oil is present in the intertidal zone, it will probably mix with suspended particles and adsorb to them. The particles of sediment and adsorbed oil

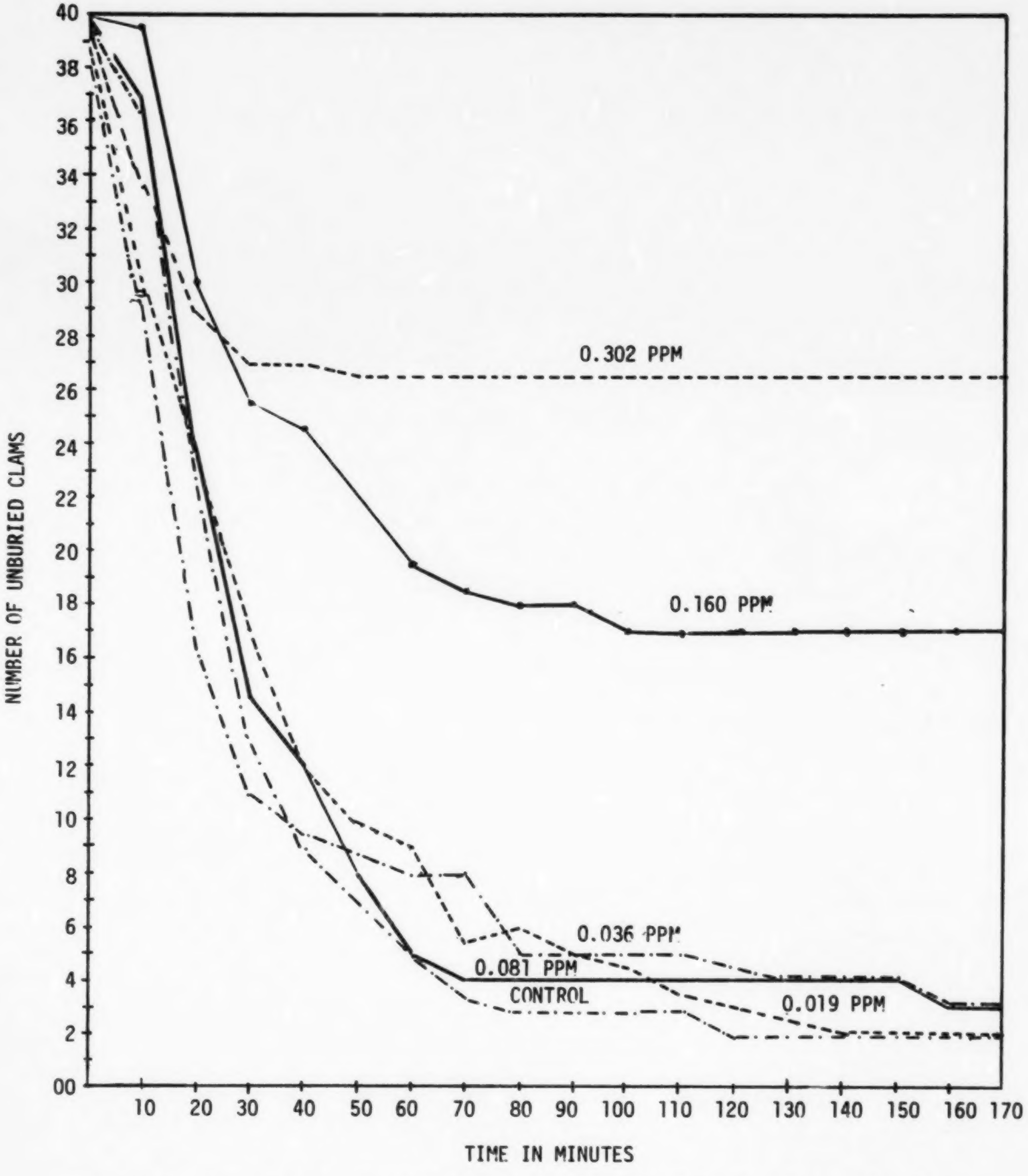


Figure 5. Response of unburied clams put into WSF of Prudhoe Bay crude oil at time 0. The points after time 0 record the progress of each group of clams in burrowing themselves into the sediment. The experiment was conducted in a flow-through system with marked clams. Concentrations are expressed as naphthalene equivalents.

will later settle, forming a surface layer of contaminated sediment. We tested the effect of such sediments on *Macoma balthica*. In our experiment oil-contaminated sediment is suspended in seawater and later allowed to settle over the surface of an established clam bed.

Experimental Design

Each exposure in this experiment was conducted in a stainless steel tray (26 cm wide by 40 cm long by 8 cm deep) completely filled with non-oiled screened mud and submerged in a larger seawater tank (37 cm wide by 53 cm long by 8 cm deep). Water temperature ranged between 9° and 12°C. Fresh seawater from Auke Bay flowed continually at the rate of 1.2 ℓ min^{-1} throughout the experiment except on day 0 when the water flow was interrupted for 24 hrs while sediment was added.

Oil-contaminated sediment for exposures or uncontaminated sediment for controls was allowed to settle over the trays of clams on day 0 to constitute exposure. The depth of the contaminated sediment allowed to settle over the trays was varied experimentally to form three different doses: 0.1 cm, 0.25 cm, and 0.5 cm. There was a control of the same depth of uncontaminated sediment corresponding to each of the three oil-contaminated sediment doses. The sample size was about 200 clams for each exposure.

Preparation of Oil-Contaminated Sediment for Use in Exposures

Oil-contaminated sediment was prepared by mixing 1 part Prudhoe Bay crude oil with 2 parts dry sediment (collected at Amalga Harbor, the source of experimental clams) and 10 parts seawater (1/2 ℓ oil: 1 ℓ sediment: 5 ℓ sw) in 1-gallon bottles and mixing in an oscillating shaker for 1 hr. The mixture was allowed to separate for 1 hr and the liquid decanted and discarded. The containers with the retained sediment were refilled with seawater and mixed for an additional 30 min and then allowed to separate for 1 hr, at which time the liquid was again decanted and discarded. Uncontaminated sediment for control was made in the same manner, with the exception that no oil was put in the mix. The mixture was made just prior to its use in exposure.

Experimental Methods

The trays of untreated mud were set up 3 days prior to the start of the experiment in the seawater tanks and seeded with 200 clams. Clams that did not bury themselves within 3 days were removed, which reduced the sample size to about 190.

On day 0 in the experiment (3 September 1975), the water in the tanks was turned off and drained. An appropriate amount of sediment was shaken with seawater into suspension and poured into the tanks. It was allowed to settle 24 hrs and then the water flow was continued. Temperature did not exceed 12°C at the end of the 24 hr period, but oxygen concentrations were not determined.

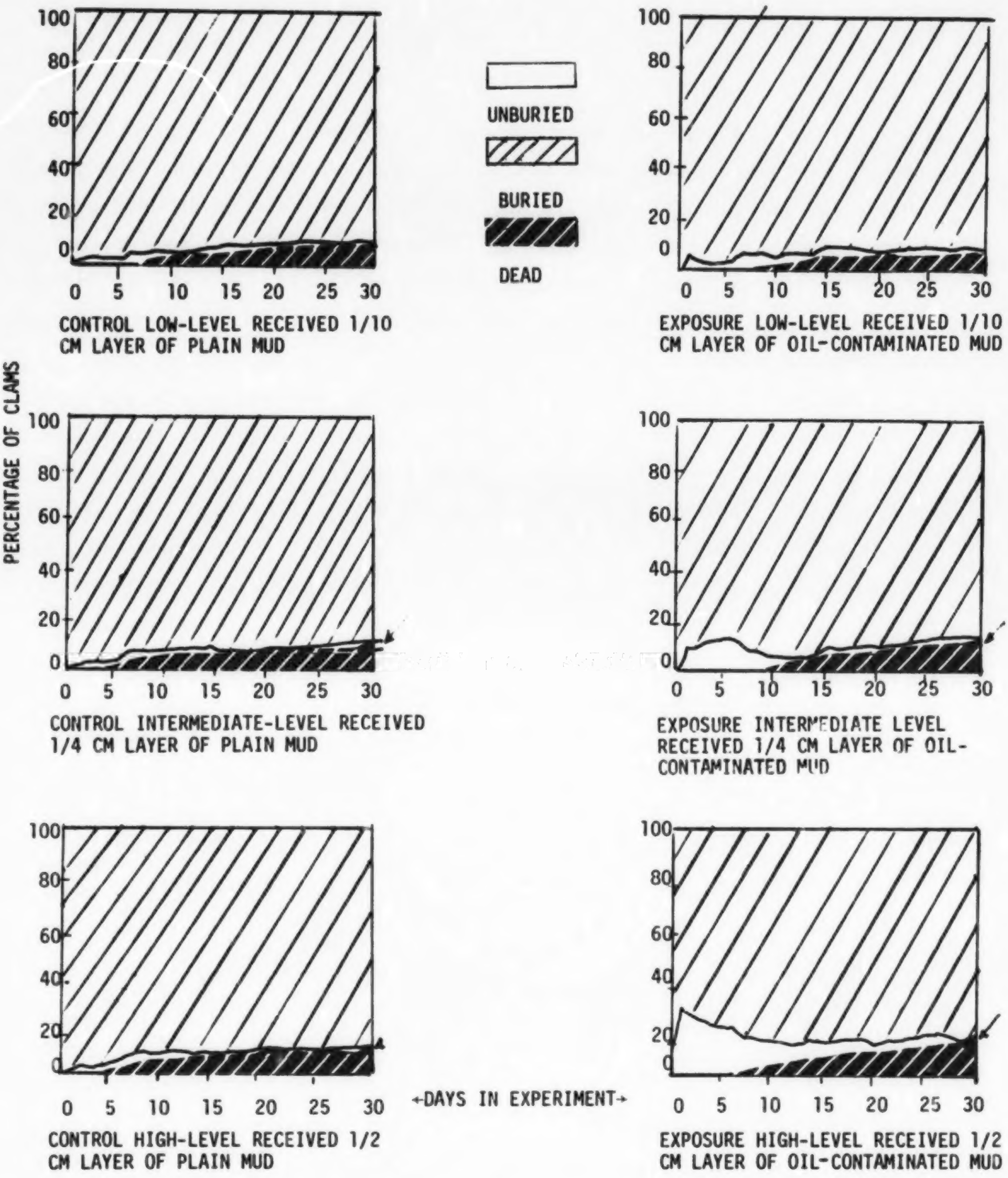
Before sediment was added, a small Petri dish was placed in each tank beside the clam trays to catch an equivalent layer of sediment and confirm the actual depth of sediment added.

Counts of clams that had responsed by burrowing to the surface or dying were made on days 1, 2, 3, 5, 6, 7, 8, 9, 12, 13, 14, 15, 16, 19, 20, 21, 23, 26, 29, and 30.

Response statistics were analyzed by computerized probit analysis (Finney, 1971)[8] and a comparison of two observed proportions analysis made (Natrella, 1966, p. ORDP 20-111)[10]. Results of the probit program are expressed as the calculated depth of sediment (cm) at which 50% of the clams will move to the surface within a specified period of time (ECm) together with the 95% confidence interval of that dose level. These data were adjusted through Abbott's formula (Finney, 1971, p. 125)[8] to correct for partial response from the control clams.

Results and Discussion

Death as a result of oil-contaminated sediment exposure was significant (Natrella, 1966)[10] in the 0.5 cm dose of oil-contaminated sediment (Figure 6), but death of clams at the 0.25 cm dose was only slightly greater than death in the controls. Death of clams in the 0.1 cm dose was similar to that of the controls. Most clams came to the surface before dying and only a small portion of dead clams were found buried (Figure 6).



CONTROL LOW-LEVEL RECEIVED 1/10 CM LAYER OF PLAIN MUD

EXPOSURE LOW-LEVEL RECEIVED 1/10 CM LAYER OF OIL-CONTAMINATED MUD

CONTROL INTERMEDIATE-LEVEL RECEIVED 1/4 CM LAYER OF PLAIN MUD

EXPOSURE INTERMEDIATE LEVEL RECEIVED 1/4 CM LAYER OF OIL-CONTAMINATED MUD

CONTROL HIGH-LEVEL RECEIVED 1/2 CM LAYER OF PLAIN MUD

EXPOSURE HIGH-LEVEL RECEIVED 1/2 CM LAYER OF OIL-CONTAMINATED MUD

Figure 6. Results of oil-contaminated sediment experiment. Each graph below represents a control or exposure dose; each dose has a corresponding control: Low level exposure-low level control. The graphs are plotted so that the percentage of clams buried, unburied, or dead are accounted for. Observations were taken on days 1, 2, 3, 5, 6, 7, 8, 9, 12, 13, 14, 15, 16, 19, 20, 21, 23, 26, 29, and 30. The arrows in the lower graphs indicate the areas of solid shading that represent the percentage of dead clams not visible at the surface.

In both control and exposure doses, increasing numbers of clams came to the surface and died over the 30-day experimental period. The gradual increases in both the controls and exposures indicate to us that there is stress either from the addition of sediment, experimental set-up, or initial condition of the clams. Responses occurring in the three control doses of non-oiled sediment were approximately equal and therefore not dependent on depth of sediment added.

The major observation in oil-contaminated sediment tests was that many clams moved to the surface after exposure but did not die. Numbers of individuals at the surface were proportional to the depth of the oil-sediment film added (Figure 6). Response after 24 hrs was linear with respect to sediment depth squared (Figure 7). In our heaviest dose (oil-contaminated sediment approximately 0.5 cm deep) 29% moved to the surface within 24 hrs (Figure 8). In the intermediate dose (oil-contaminated sediment approximately 0.25 cm deep) 10% moved to the surface within 24 hrs, while 6% of the clams at the lowest dose (0.10 cm) surfaced. Less than 2% of the control clams came to the surface within this period of time.

The depth of sediment calculated by probit that it would take under conditions of the experiment to stimulate 50% of the clams to move to the surface within 1 day is 0.668 cm, with 95% confidence intervals of 0.758 and 0.579.

OVERALL DISCUSSION

From the results of these three types of experiments, it seems apparent that the impact of an oil spill on *Macoma balthica* depends on the amount and location of mixing energy applied to the sediments and/or seawater. If there is essentially no mixing energy associated with a spill, such as we had in our unmixed crude oil spill, effects will probably be negligible. If there is enough mixing energy offshore to form WSF's of oil, these may move in over the clam beds and if concentrated enough affect the burrowing activities of clams. If there is mixing energy in the intertidal zone, both WSF and oil-contaminated sediment may form. Such contaminants will result in inhibited clam burrowing activity, movement to

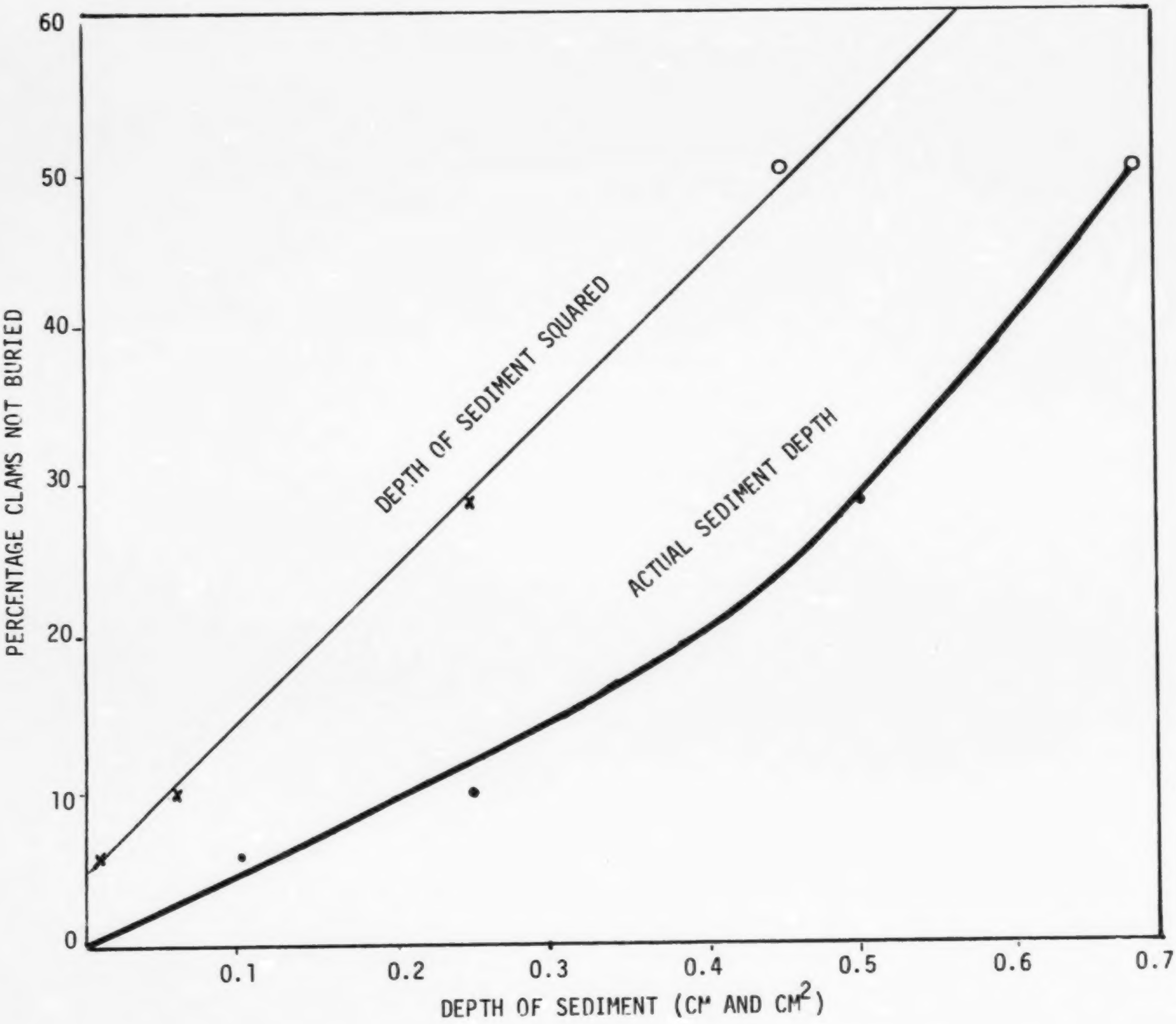


Figure 7. Percentage of clams responding to oil-contaminated sediment by coming to the surface at 24 hours versus depth of sediment (solid circles) and depth of sediment squared (x's). Open circles represent ECm values calculated by probit.

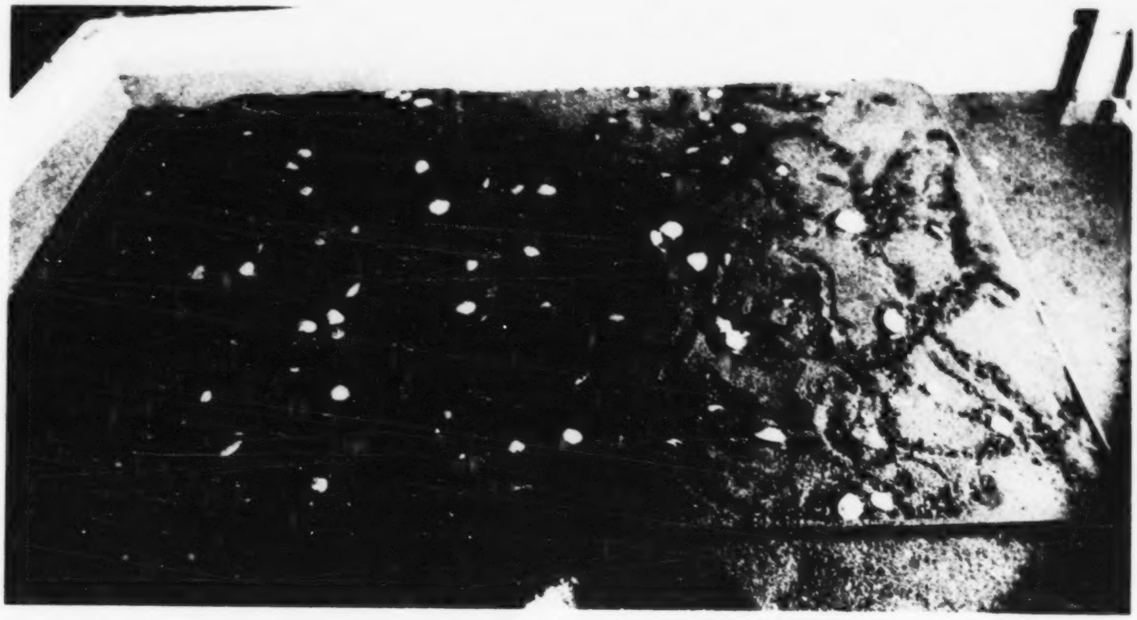


Figure 8. Photograph of clams in high level exposure (1/2 cm) to oil-contaminated mud, taken 24 hours after start of exposure. No clams appeared on the surface of control sediments.

the surface, and presumably death of exposed clams either from toxicity of the oil, exposure to adverse environmental conditions, or increased predation.

In our experiments there was a trend of clams first coming to the surface and a portion of them later dying (Figures 3 and 6). A very small percentage of the clams that died were not immediately visible at the surface, but were later discovered when the mud was screened at the end of the experiment. If this trend is the same under natural conditions, it is possible that there was a much greater effect of the oil on the clams in the Valdez field experiment of Shaw *et al.* (1976)[5] than is indicated by their data, since the aluminum containment frames used in their study were not designed to retain clams that might come to the surface. Many clams may have come to the surface after oil exposure and could have died, floated away, or been taken by predators while still living but exposed on the sediment surface.

Throughout our work with *M. balthica* we observed deposit-feeding activities only during April, May, and June, when Experiment 1 was underway. In late summer, fall, and winter no deposit-feeding was observed in either control or exposed clams. Because we conducted our WSF and sediment experiments during this later period and still got a response to oil, we conclude that the response is not only dependent on direct ingestion but also hydrocarbons must enter or affect the clams through respiration or direct transport through membranes.

Although several questions regarding the responses of *M. balthica* to hydrocarbon remain to be answered, the results of this study lead us to agree with Shaw *et al.* (1976)[5] that *M. balthica* shows potential as an indicator of oil pollution. Our results suggest that the actual and ecological death of *M. balthica* upon exposure to oil-contaminated sediments and dissolved oils may be even greater than is indicated by the mortality reported by Shaw *et al.* (1976)[5]. The responses of clams proportional to oil dose as observed in our study over both short- and long-term exposures suggest that these small clams are a good bioassay organism and well suited for use in baseline studies. Even though few of the clams die upon short-term exposure to the water-soluble fractions of crude oil or oil-contaminated sediments, their immediate behavioral response to oil in their environment may result in ecological death.

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APPENDIX B

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